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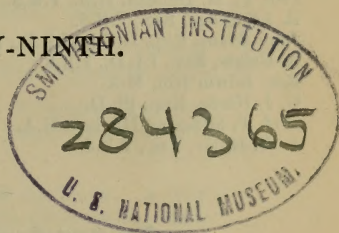
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Quod si cui mortalium cordi et curæ sit non tantum inventis hæere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant. —*Novum Organum, Præfatio.*

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1. *The HORNBLENDIC and other SCHISTS of the LIZARD DISTRICT, with some additional Notes on the SERPENTINE.* By T. G. BONNEY, M.A., F.R.S., Sec. G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read November 1, 1882.)

[PLATE I.]

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I. *Preliminary.*

IN my paper on the serpentine and associated rocks of the Lizard district\*, I made a few remarks only on the hornblendic and other schists, as the investigation of that series was foreign to the purpose then in hand, and in the concluding paragraphs I incidentally mentioned it as being "probably about Lower Devonian age." Soon after the publication of that paper I began to pay special attention

\* Quart. Journ. Geol. Soc. vol. xxxiii. p. 884.

to the structure of metamorphic rocks of sedimentary origin, and before long to feel the gravest doubts as to the possibility of the great mass of schists associated with the Lizard serpentines being of the same age as the slaty and little-altered Cornish strata, which belong mainly, if not altogether, to the later Palæozoic period. Each year's experience with the microscope and in other regions did but strengthen this conviction, which of late I have ventured to express frequently; but it was not until last Easter vacation that I was enabled to revisit the Lizard. In about ten days of hard work I examined with considerable care the coast sections of "hornblende schists," as indicated on Sir H. De la Beche's map, from the Lizard Head to Porthalla on the east, and to Polurrian Cove on the west. During the major part of this time I had the advantage of being accompanied by my friend and former colleague the Rev. E. Hill, Tutor of St. John's College, Cambridge, whose friendly aid I most gratefully acknowledge. A large series of specimens was collected, and evidence obtained, which to my mind is conclusive as to the vast difference in age between the "hornblende schists" and the slaty group. A number of the specimens have subsequently been examined microscopically, and the results are embodied in the following paper, together with some account of two outlying masses of serpentine, which I had previously been obliged to leave unvisited.

As on former occasions, Sir H. De la Beche's Geological Memoir of Cornwall and Devon was constantly in my hands, and I cannot forbear again expressing my sense of its thoroughness and value. There are, indeed, some points on which I come to different conclusions; but this is simply because I have had the advantage of using the microscope; and as regards most of these, I believe that the author had expressed himself more or less doubtfully. Each day's work has but increased my admiration of the genius of the first chief of the British Geological Survey; and I will venture to say that if he could have had the advantages which we now possess, he would have left little for our generation to do in Cornwall.

## II. *Stratigraphy of the Metamorphic Sedimentary Series and its Relation to other rocks.*

In the paper to which I have referred, I state that in addition to the "talco-micaceous" schists of De la Beche and the normal hornblende schists, there is a third group of greyish granitoid rocks, composed mainly of quartz and felspar, sometimes almost a quartzite, sometimes simulating a vein-granite, associated with more hornblendic, chloritic, earthy, and (as I should have added) micaceous layers. I may refer to pages 885-7 for a sketch of the general petrology of the series; but on the present occasion, besides supplying many details, I trust to be able to show that there is, in addition to the "talco-micaceous" and the "hornblende-schist" group already recognized, a third or granulitic group. These, however, form but one series, enumerated in ascending order, the first being characterized by rather compact dull-green schists, whose exact mineral composition cannot readily be decided in the field, and by brownish



mica-schists; the second by black lustrous hornblende schists, sometimes rather massive, sometimes beautifully banded with felspar or epidote; the third by pinkish-grey quartz-felspar rock closely interbanded with dark hornblendic or micaceous layers.

I will commence my description with the southern coast of the Lizard, in which the lowest of these groups is well exposed. In places the cliffs forbid a close examination; but we are able to descend to the sea from time to time so as to obtain a good general idea of the group as a whole. It is, however, difficult from the above cause, from the want of conspicuous characteristics in the different beds, and from the frequency of dislocations\*, to establish a very exact succession in the minor subdivisions. At the south-west angle of the Lizard Head, called the Quadrant, we find the following series:—a thick mass of corrugated greenish schist, with “cherty” bands, over which is a quartzose rock of rather gneissic aspect (p. 12) overlain by fissile green schist, whose constituents are so minute as to give it a slaty look. These have a general E.S.E. dip of about 25°. At the top of the headland, a little further to the N., is a quartzose schist with a slightly steeper dip. I think that these beds are the lowest visible in the series. The coast-line indeed from this point to the serpentine at the south end of Pentreath beach runs nearly N., and S.; but there is much disturbance, and some discordance in the dips. On the whole it is my impression, in accordance with Sir H. De la Beche’s views, that we reach higher beds in going northward. At Caerthillian (about a furlong south of the serpentine) the hornblende schist proper is mapped as brought in by a fault. The beds are not in a condition very favourable for examination; there is undoubtedly a fault beyond which are some hornblendic bands; but on the whole I am inclined to include all or almost all these beds in the lowest or “talco-micaceous” group of De la Beche, and think that there is no important dislocation.

Proceeding eastwards from the Quadrant along the cliffs (which face south), we walk over a series of greenish micaceous schists of rather uniform character, until we descend to the sea at Polpeor, and are able to pass for some little distance at the base of the cliffs. The lowest part of these (well shown in a tiny cove on the west of the little beach) consists of a green epidotic schist in thick bands, alternating with brownish very micaceous schist, and with occasional lenticular hornblendic bands, sometimes exhibiting imperfect crystals or “eyes” of whitish felspar, which last rock has a resemblance to the typical hornblende schist of the Lizard district. The general dip is to E.N.E., about 40°. These beds continue to the main cove, being often beautifully corrugated on a small scale, and are exposed in the road descending to the beach. The headland bounding the cove on the east consists of a greenish schist with fairly well-marked foliation, but very minute constituents, which becomes at times epidotic.

\* Faults abound in the Lizard district; they will be noted in almost every cove, inlet, or sea-chasm (of which they are probably the cause). The generally uniform character of the rock makes it extremely difficult to estimate the amount of vertical displacement; but, as a rule, I believe it to be slight.

The general dip here is between N.E. and N.N.E. At low tide, a small intrusive mass of a porphyritic diabase\* only exposed for a few yards, and rarely more than one yard in thickness, can be seen. It is the only igneous rock which I have detected in this group.

The next cove, bounded on the east by the great headland on which stands the lighthouse, marks the junction of the micaceous with the hornblendic series. This is undoubtedly a faulted one; but I believe the displacement to be but slight, and after more than one examination I retain the opinion previously formed that there is no real stratigraphical break between the two. The headland consists of hornblende schist, the beds of which dip gently under the lighthouse; and the same rock is exposed a short distance inland on the road from Lizard Town to Polpeor Cove. From beneath the lighthouse to the Bumble Rock the crags are formed of normal hornblende schist, with fairly well-marked bedding, which, with minor rolling, dips gently to the E.N.E.

Beyond the Bumble comes Housel Bay, with its fine cliffs. Here the beds of the hornblendic series, which are slightly more massive and epidotic near the little rift at its head, appear to form a very slight synclinal followed by an anticlinal; but the strike continues W.N.W. to E.S.E., and we seem to rise a little as we proceed in an E.N.E. direction, so that on the whole the beds on the Bumble appear to underlie those of Penolver Point. On the eastern side of this headland the beds are beautifully banded, consisting of dark hornblende and whitish felspar (which weathers a light brown colour), and afford indications of false bedding. The gentle rollings continue to Beast Point, where there is rather distinct lenticular bedding, but on the whole there appears to be a gradual dip to E.N.E. At the Point itself the dip is sharper, perhaps  $30^{\circ}$ , but there is much contortion. The coast-line now has a general trend to the north, and hence to Hot Point the variable bedding and the disturbances continue. At the base of the latter locality the beds seem to be doubled up, the strike of the roll being N.N.W. Hereabouts the structure of the rock is most interesting. Lenticular bedding is frequent, there are some of the most remarkable instances of false bedding on a small scale that I have ever seen (Pl. I. fig. 2), and indications here and there of a kind of ripple-drift. It is impossible to resist the conclusion that, notwithstanding the great amount of metamorphism, we have here a record of true "current-bedding" (whether by water or by wind) in the original constituents of the rock.

\*Macroscopically it exhibits a rather compact dark grey ground-mass, in which are scattered numerous elongated crystals of a whitish waxy-looking felspar, up to about 5" in length. Microscopically the ground-mass consists of a felspathic mineral full of secondary microliths, with the original structure quite obscured, and of hornblende, often occurring in rather distinct prisms clustered together side by side, besides some grains of iron peroxide. The aspect of the hornblende suggests that it is of secondary origin. The larger crystals of felspar are also much decomposed, and all that can positively be said is that the felspar is a plagioclase. I regard the rock as a hornblendic diabase, rather than a true diorite.

From Hot Point to Perranvose Cove the more uniform dark hornblende schists continue, becoming sometimes more epidotic, sometimes slightly granitoid as we approach the latter. The dips are variable, being in one place W.N.W., with much faulting and other indications of disturbance; but on the whole the beds appear to strike towards the N.W. with a dip on the eastern side, so that we probably continue to rise in the series. The beds in the cove itself, dark hornblende schist with marked epidotic and rare quartzo-felspathic bands, have a rather gentle dip somewhat to the south of E.S.E. Dark hornblende schists with epidotic bands continue, so far as can be seen, to the bay, under the Balk Quarry, where we have the first intrusion of serpentine. On reaching the sandy shore we find here, at the southern end of the bay, a decomposed and shattered schist, probably the normal hornblendic rock, capped, in a little reef beneath the quarry, by a well-marked quartzo-felspathic band, which marks the setting in of the uppermost division of the series.

It may save time to give a brief description of the lithological characters of this group. It is generally rather distinctly stratified, beds of a fairly massive quartzose rock of a purplish-grey colour alternating with darker and more schistose bands. The former varies from a felspathic quartzite, containing occasional flakes of mica or hornblende, to a crystalline quartz-felspar rock, in hand specimens hardly distinguishable from a vein-granite. The darker layers are often rich in mica; but hornblendic or chloritic minerals are sometimes predominant. Commonly these rocks do not exhibit a very marked foliated structure. Lenticular bedding and even indications of current-bedding are far from rare, and the whole group gives one the idea of having been deposited by rather variable currents in waters of no very great depth.

The results of microscopic examination will be given below. I have felt much difficulty in giving the group a name, but think that on the whole it may best be designated as the "Granulitic group," it being understood that garnets are either wanting, or very small and inconspicuous.

The rocks of this group are well exhibited in the cliffs of the Balk Bay, where, as described in my former paper, they are broken through by serpentine and gabbro, and at low water can be followed for some little distance further north, beyond the "granite-vein," which, as explained in my former paper\*, is only one of the granitoid bands in this group. At a little headland in the bay itself the dip is about  $45^{\circ}$  N.N.E. The thickness must be considerable, not less than two or three hundred feet and perhaps more; but the interruptions caused by the intrusion of serpentine and gabbro make any estimate most difficult. Beyond this the cliffs are serpentine, and their base cannot be approached; but after about a quarter of a mile we are able to descend to the shore to Polbarrow Cove, where we find a mass of serpentine intrusive in the granulitic series; this exhibits close and streaky interbanding of the pinkish-grey and dark varieties. One band of the former, just to the south of a

\* Quart. Journ. Geol. Soc. vol. xxxiii. p. 894.



little prominence occupied by a boat-house, has a remarkable grit-like aspect (see microscopic description, p. 18). There is much local disturbance, but the general dip is about  $25^{\circ}$  N.E. On the north side of the cove serpentine with intrusive gabbro rises to the top of the cliff; these continue for a short distance till a second small cove is reached, bounded on the south by dark serpentine \* and intrusive gabbro, both of which break through the granulitic group, and on the north by the normal dark hornblende schist. The cove itself follows the line of faulting, by which the rock for a short distance seems completely 'smashed.'

The latter group was examined from above down to the sea at Carnbarrow. It is the normal dark hornblende schist, with the usual specks and imperfect bands of white felspar, which in one place shows remarkable indications of current-bedding. The beds dip to N.E. or a little N. of this at about  $20^{\circ}$  to  $30^{\circ}$ . In the small quarry above Dolor Hugo, where the general dip is about N.E., the highest rock begins to bear some resemblance to the granulitic group. The sedimentary beds on either side of the "Frying Pan" belong to the granulitic group, and though locally much disturbed by intrusions of serpentine, appear to have a general dip to the N.N.E. at about  $20^{\circ}$ .

A great fault passes down Cadgwith Cove and brings in again the dark hornblende schist with epidotic bands and indications of current-bedding (p. 16), similar to what we find above the middle part of this group. The general dip is between N.N.W. and N.W., and about  $35^{\circ}$ .

These dark hornblendic rocks continue with a fairly steady dip until, after passing another small cove, we come to the (red) serpentine quarry on Ynys Head, where that rock is intrusive in a mass of the granulitic group, which also crops out among the serpentine in the headland immediately to the north. The general dip of the stratified series is north-westerly, and at about  $30^{\circ}$ . A little beyond is a bowl-like corrie with indications of a landslip, which leads us down to the sea. Here we have the black serpentine breaking through and overlying the granulitic group, which is exposed in at least three places, the largest mass, on the southern side of the recess, dipping roughly W.N.W. A thick dyke of coarse gabbro, conspicuously foliated towards the exterior, runs obliquely up the cliff. Some of the diallage crystals are of great size; one, which appeared fairly uninterrupted, was more than four inches across.

The sedimentary rocks seen on each side of Caerleon Cove†, described in my last paper, belong to the granulitic group with pseudo-granitic bands as at the Balk. In some cases the layers of granitoid and of dark hornblendic or micaceous rock alternate rapidly, the thickness being from 3" downwards.

The details of the coast rock of Caerleon are given in my former paper, as well as those in Kennack, so that it will suffice to say that the sedimentary rocks belong to the granulitic group, and in the

\* The variety found abundantly north of Cadgwith.

† I again examined the diorite dyke (described p. 900). I am now quite sure that there is no hornblende schist entangled in it.



latter seem to form a kind of littoral fringe to the great mass of serpentine inland. Some of the former show very interesting interbanding of the granitoid and dark varieties, layers from less than half an inch to an inch setting in and dying out—indicating almost certainly lenticular bedding (Pl. I. fig. 1). This is seen on a larger scale in the granitoid rock at the north end of the cove described in my last paper (p. 901)\*.

We seem then to have satisfactory evidence from these sections along the eastern coast that the rather uniform and thick mass of hornblende schist passes upwards into a more variable group, characterized by the presence of quartzo-felspathic bands, which can hardly be less than two or three hundred feet thick, and may be more.

The coast for some miles northward is occupied by serpentine and gabbro, and a great part has been minutely described in my former paper; but as hornblende schist is not marked on the map, and as I had no recollection of seeing any, I did not think it necessary on the present occasion to examine this, but commenced again at Porthoustock Cove, to the north of the great mass of "greenstone" forming Manacle Point, at which my former work ended. The cliffs on the southern side of the cove consist of "greenstone"†. On the

\* At the base of the rocky projection which divides Kennack Cove into two bays a singular rock occurs, as to the nature of which I feel much difficulty in coming to a conclusion. It consists mainly of a finely crystalline mixture of felspar, hornblende, and brown mica, with a slight indication of parallelism in its mineral structure; but here and there it seems to become porphyritic or is spotted with patches of a felspathic mineral and a dull green, rather fibrous, hornblende like some of the altered gabbros on this coast; many of these seeming enclosures vary up to about 3" across, but sometimes they are as much as a foot or two wide. The appearance suggests that we have here a mass of igneous rock which has broken through and brought up with it a number of fragments of gabbro. The mass includes bands resembling the granitoid rock of the neighbourhood, and appears to end rather abruptly. Felspar veins traverse it and add to the confusion. Microscopically it consists of a rather pale green hornblende, felspar mostly replaced by microlithic secondary products, some rather altered brown mica, together with some apatite, black iron-peroxide, and a little quartz. Here and there are aggregated grains of rounded outline and minute granular structure, which, with crossed Nicols, give a minute speckling of different rather bright colours. This mineral is often associated with grains of magnetite (?) and sometimes seems to enclose them. The hornblende resembles that already described from a dyke in Kennack Cove (vol. xxxiii. p. 901), and has the look of a "uralitic" mineral. The felspar, however, seems to have been in rather rounded grains, not in the elongated prisms common in dolerite; we meet, however, with the former shape in gabbros and some diorites, so that I incline, though not without hesitation, to regard this as an igneous rock.

† Two specimens of this have been microscopically examined. Both exhibit rather elongated crystals of a plagioclastic felspar, considerably decomposed, extinguishing at angles which are most in agreement with those of labradorite, together with hornblende, which, from its irregular external form, its feeble dichroism and absence of characteristic cleavage, I believe to be a secondary product. There are specks and rods of opacite with a little ilmenite (probably) and pyrite. The rock was probably once a dolerite, and so may be named a hornblendic diabase.

The above is cut by a dyke of felspathic gabbro. This sends off veins into the adjacent rock, and its greatest thickness is about 4'. It consists of a rather decomposed plagioclastic felspar, with the "granular" outlines usual in gabbro, agreeing best with labradorite, and of a green mineral, which often occurs as

northern side they are hornblende schist. The upper part of this is rather homogeneous in structure and very dark in colour, the bedding (with the foliation) dipping at about  $20^{\circ}$  to W. or a little S. of that. There are occasional "eyes" of a white felspathic mineral; and this structure becomes more marked as we proceed (descending in the series) along the coast, becoming very marked at a little headland where the dip is rather to the N. of W., and more gentle. There is evidently a roll over in the beds near Penner Head, as noted by Sir H. De la Beche. We were not able to examine this part of the coast very minutely; but the general character of the rocks agrees with that of the middle or hornblendic group of the south. The first mass of serpentine is in a small cove between Maentallach rock and Polkerris Point; but I reserve for the present the description of this and of the larger mass to the north\*. We traversed Polkerris Point rapidly, but all the rock which we saw appeared to be generally similar to that first mentioned, and we scrutinized carefully the interesting coast-section between this and the village of Porthalla. It will be more convenient to describe this in the reverse direction. The cliffs on the northern side of this cove consist of a brownish shaly or slaty mudstone, at times slightly micaceous. This may be traced on the southern side of the cove for a few dozen yards, and then the rocks are completely smashed up by a great dislocation, on the other side of which we find the metamorphic series. The lowest rocks seen consist of compact chloritic or micaceous schists of a greenish colour, which much resemble the lowest group of the south coast; but among them is a marked granitoid band a few feet thick, exactly like one of those which further south characterize the uppermost group. It dips very sharply away from the fault (*i. e.* to the east or south-east); but the disturbances due to this and to the intrusive mass of serpentine just beyond make it impossible to place any confidence in observations. The ground also is a good deal masked by fallen débris, grass, and heather; but after much scrambling up and down the hillside on the western edge of the serpentine, I came to the conclusion that these micaceous beds underlie normal hornblendic schist, which is well exposed in the upper part of the hill to the west of the serpentine. It is much rolled and contorted, with a strike roughly varying from the W.N.W. to the N.N.E.

The serpentine is well exposed, both in a small quarry on the

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an aggregated mass of minute prisms and belonites, and is evidently a secondary product. The more distinctive forms are undoubtedly hornblende, and the general outline of the patches suggests that it has replaced diallage. There are some iron-peroxides, among which ilmenite can be recognized. The slide is rather rich in apatite, the longest prisms being .08". The general aspect of this rock corresponds fairly well with that of the district near Coverack; but when I examined the latter I was under the impression that the gabbro was cut by the greenstone (p. 913). I was, however, obliged to traverse the ground rapidly, and did not return, as the relations of these rocks had no bearing on the main objects of my paper, so I may have fallen into error.

\* There is also a little gabbro of the ordinary type, but I did not see a good exposure.

hillside, near to which a junction is seen with banded hornblende schist (generally similar to that just mentioned), and down on the rocky shore at low water, where this rock and its junction with the hornblendic series may be studied to great advantage, and some interesting facts observed which will be noticed below. Altogether there is a considerable mass of serpentine, beyond which a distinctly banded whitish and dark greenish hornblende schist can be traced up from the sea, forming the whole mass of this part of the hill. The dip at first varies towards either side of north, with much disturbance and rolling; then it becomes N.W., and, finally, at about one third of a mile from Porthalla, it is almost N.N.W., the angle being nearly  $50^{\circ}$ .

The slaty rock, which extends from Porthalla Cove northwards, has been excellently described by Sir H. De la Beche; and I only made a rapid traverse as soon as I had satisfied myself that it had no claim to be called a foliated rock, and exhibited no marked metamorphism, unless a probable slaty cleavage (coincident with bedding) be so called. Hence I content myself with referring to the microscopic structure of the generally similar series on the western coast (p. 11), and, passing over the quartzose and calcareous bands, at which I have merely glanced, proceed on to a locality to which, as having an important bearing on the relation to the hornblende-schist series, I paid particular attention. Sir H. De la Beche draws attention to three conglomerates which he observed in this slaty series. The most distant of these I had not time to visit; but I made a brief examination of that west of the Nare Point and a much longer one of that to the south of it. The former is peculiar. I did not notice the rounded quartz pebbles mentioned by Sir H. De la Beche, and the majority of the blocks are but little rounded; some have a vesicular aspect and resemble a dark greenstone. I thought this might possibly be an agglomerate; but a specimen examined microscopically proves to be a dark quartz grit, such as might have come from one of the older Palæozoic rocks. As to the character of the bed south of the Nare Point, there can be no doubt it is a true conglomerate, containing in a dull-grey muddy-looking matrix angular fragments of dark slaty rock, of a kind of dark "greywacke," of vein-quartz, and a quartzo-felspathic rock bearing some resemblance to the pseudogranitic bands already mentioned\*; the last two are pretty well rounded, as if they had travelled further than the other. The materials of the conglomerate vary much in size; sometimes they are quite small, sometimes (especially in the upper part) up to, and even exceeding, a foot in

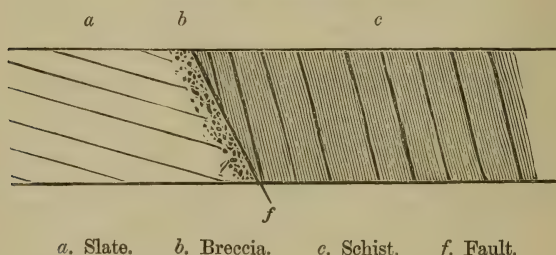
\* Microscopic examination shows it to be a true gneiss, though not one of the most conspicuously foliated varieties. It consists of quartz, often in aggregated patches of grains of different sizes, feldspar (orthoclase, with some albite or oligoclase, and possibly a little microcline), a fair quantity of colourless mica (probably one of the hydrous potash or soda group), and a less amount of a much altered magnesia-iron mica.

This specimen has more white mica than is usual in the granulitic group, and may have come from some other series, such as that to which belong the gneisses near the Eddystone.



diameter. Sir H. De la Beche mentions the occasional occurrence of fragments of hornblende schist; but as he sometimes permits himself (as was at that time inevitable) a little laxity in the use of the term, I was anxious to settle a point obviously of the first importance with relation to the age of the two series. After a prolonged search, I at last succeeded in discovering an indubitable fragment of hornblende schist, and so corroborating his statement. The fragments are rare; for it was not till my second visit, and after searching for at least an hour, that I found it. The quartz-felspar pebbles also clearly come from a metamorphic series, if not from the exact horizon that I have mentioned, so that there can be henceforth no question that the two series are separated by an enormous interval of time, and that there is no approach to a passage of the slaty mudstones into the hornblende schist.

*Section in Polurrian Cove.*



*a. Slate. b. Breccia. c. Schist. f. Fault.*

Turning now to the junction of the slaty with the hornblendic series in Polurrian Cove, on the western coast, we find similar evidence of the complete separation of the two. The former is a smooth, satiny, blackish or brownish slaty rock, veined occasionally with quartz and calcite, in which are lenticular sandy bands, dipping generally about  $30^{\circ}$  E.S.E. The hornblendic series is very massive, resembling at first sight a decomposed greenstone, but disclosing on closer examination indubitable signs of foliation and bedding: it dips at about  $70^{\circ}$  S. At the junction is a fault-breccia, a yard or two thick, composed mainly, if not wholly, of fragments of the newer series in a rusty-looking matrix\*. The above diagram shows the general relations of the two series. The two rocks on opposite sides of the fault are as different lithologically as is possible, the one being almost unaltered†, the other as highly metamorphosed as is possible.

\* This is described by Sir H. De la Beche, though with much hesitation, as a conglomerate. I think that there is a better exposure now than on the occasion of his visits, and that there can be no doubt on the matter.

† I believe there is a true cleavage, but correspondent with the bedding; the surfaces of this have been rumpled by subsequent lateral pressure, which has left its mark on the microscopic structure of the rock. This would be termed a "phyllite" by many continental geologists, and much resembles some specimens



Proceeding southwards, along the foot of the cliffs, the dip of the hornblende schist soon changes to S.W.: on the south side of a little cove it becomes (being very steep) W.S.W., and on the other side of a jutting headland is even slightly north of west. The rock now exhibits the white spots or "eyes" of feldspathic mineral, and, as we rise in the series, shows epidotic bands, and then becomes markedly striped with whitish and blackish layers. By the signal-station on Henscarth the banded hornblende schist (rather contorted) has a high W.N.W. dip (over  $70^{\circ}$ ). In the neighbourhood of Mullion Cove the banded hornblende schist is considerably crumpled\* and disturbed, and the final dip, where it meets the great mass of serpentine on the southern side of the cove, is a high one to E.N.E. This mass of serpentine is probably bounded on both sides by faults; the hornblende schist, of the ordinary banded type, south of it dips  $45^{\circ}$  N.E. (in the notch where the streamlet from Higher Pradanack tumbles to the sea), and continues for some time about E.N.E., changing near Pedencrifton to W.S.W. (about  $50^{\circ}$ ). Further south, on Pradanack Point, the schist becomes very massive, in hand specimens resembling a diorite, and continues to dip steeply towards the west. On the line of cliffs fronting the south, near Ugethawr, the beds are almost vertical, but incline to the S.W.; and this general dip continues, becoming less steep and with much local disturbance, till we come to the serpentine at Ugethawr. This rock continues till we again reach the schistose series, as already described, at the south end of Pentreath Beach†.

It appears, then, as the result of the above observations, that in

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in the "Étage Revinien" of the Ardennes. I have examined microscopically two specimens, one from a micaceous sandy band on the north side of the cove, the other a typical specimen of the slaty rock. The former consists of angular and subangular fragments of quartz imbedded in a minutely granular earthy-looking ground-mass, the result of decomposition of feldspathic constituents, with many scales of micaceous minerals; of these some are colourless, possibly belonging to the hydrous soda or potash group, others are a brown mica; minute granules of ferrite, opacite, possibly of graphite, abound, and irregular ferrite-stained cracks traverse the slide, roughly following the bedding. The majority of the minerals are clearly of clastic origin, and the amount of metamorphism is not great. In the phyllite the micaceous and feldspathic constituents predominate, but there are still abundant grains of clastic quartz, though more minute; opacite occurs plentifully with an arrangement somewhat similar to the last, and there are indications of subsequent crumpling. It is less easy to be sure of the origin of the mineral constituents of this rock, owing to their small size; but I am convinced that though there has probably been a certain subsequent development of sericite and other microliths, all the larger constituents are of clastic origin, and the amount of metamorphism is less than is found in most chistolites and "spotted" slates.

\* I noted W.N.W., W.S.W., and E.N.E. dips there, which clearly proves rolling: the junction with the serpentine on this "side of the cove" is, I believe, a fault; the copper-mine appears to have been opened in the fault-breccia on the boundary.

† The small knolls of hornblende schist exposed near Kynance, on the shore, described in my former paper (pp. 888-9), belong to the banded part of the series. I reexamined the singular variety there described, which may possibly indicate a reappearance of the schist *in situ*, and feel satisfied now that it is not an igneous rock.

the southern district, where we have the longest succession of the hornblendic series, though not the largest area, the dominant strikes vary from W.N.W. to N.N.W., and so may be described as roughly N.W. to S.E. This continues as far as the neighbourhood of Cadgwith, after which the strikes are more discordant; but on the western coast we have the same tendency to a N.W. strike, with now and then, as in the other regions, a deviation to the eastern side of north. Sir Henry De la Beche's record over the northern area of the hornblende schist gives a general W.N.W. strike, so that we may pay less attention to the observations near Porthalla, and say that the normal strike of the metamorphic series is roughly N.W.-S.E., the beds ascending in the easterly direction. Taking  $1\frac{1}{4}$  mile (6600 feet) as the breadth of the series exposed in the southern area, measured from S.W. to N.E., and  $30^\circ$  as the average dip, the maximum thickness of the whole series would be 3300 feet, of which rather less than three fourths would belong to the hornblendic group, and perhaps 300 feet or so to the uppermost group; but this total estimate may well be considerably in excess of the truth.

### III. *Microscopic Structure of the Metamorphic Series.*

#### A. *Micaceous Group.*

This group, as has been already said, is well marked in its lithological characters, consisting chiefly of a number of somewhat compact dull-green schists, often with a rather "satiny" lustre, composed evidently of very minute constituents, moderately fissile, with sometimes a slightly flinty fracture, not seldom very beautifully corrugated. With these are associated occasionally very distinctive mica-schists, and others that are hornblendic, the latter mineral, however, being a dull green, and not the black lustrous variety common in the group above. As will be seen, the green constituent appears very generally to be a variety of hornblende rather than a chlorite (indubitable specimens of which do not seem common) or a mica; but as the latter mineral is not seldom present, and predominates in some bands, I have given this distinctive name to the group.

Several specimens have been examined microscopically. I will describe first a series collected at the Quadrant, taken in ascending order. (1) A dull green schist, mottled with ashy white (p. 3). It is a distinctly foliated rock, the green constituent being, for the most part, a hornblende in minute rather irregularly formed prisms, with a green mica, probably an altered biotite, and a white mica; associated with the latter is a peculiar mineral of rather fibrous irregular structure, possibly sillimanite. There is a fair amount of quartz in parts of the slide. The whiter patches consist of a granular mineral, composed of minute aggregates, whose nature I cannot determine, with, in parts, much ferrite. Possibly it replaces a felspathic constituent. (2) A greyish rock of somewhat gneissose aspect (p. 3). It consists of quartz in granules of irregular outline and very variable size, but rarely exceeding .02", about the same quantity of grains of

a felspathic mineral, also of irregular outline, now replaced by microliths of secondary origin, a good deal of green mica, and but little hornblende. Minute enclosures are numerous in the quartz, some being cavities. Bubbles, if indeed they occur, are very minute; ferrite, opacite, and a little epidote are present in the slide. (3) A dull-green, fairly fissile schist (p. 3), consists of hornblende in small prisms, with the angles slightly rounded, ranging generally from  $\cdot001''$  to  $\cdot005''$  in length, sometimes a little longer, but oftener smaller, only one or two of which show cleavage-planes. It is of a pale-green colour and moderately dichroic; with this, often in large plates, is a pale-green fibrous mineral associated with opacite and ferrite microliths, doubtless an altered biotite. The quartz contains included microliths of hornblende and ferrite, with possibly some minute cavities. The minerals exhibit a wavy parallelism. (4) Compact rather quartzose green schist at the top of the Quadrant Headland (p. 3); not very markedly foliated, consists chiefly of well-marked quartz grains, with flakes and belonites of a pale-green, rather fibrous, mineral. Some of this extinguishes as a mica, some as a hornblende, so that we have a mixture of the two minerals. The quartz is generally clear, with but few cavities and these very minute; microliths of hornblende(?) are sometimes present in them. There is also a fair quantity of a peculiar earthy-looking mineral, some of which may be epidote; this also occurs in some irregular divisional planes cutting across those of foliation; ferrite and opacite are scattered about the slide, with a few small colourless garnets. (5) A rather compact, finely corrugated, dull-green schist from beneath brownish mica-schist west of Polpeor (p. 3). This consists of hornblende (abundant) in rather elongated prisms, ranging commonly from about  $\cdot01$  inch long to mere microliths, their longer axes roughly parallel; quartz is mixed with this, and here and there occurs in more distinct bands. Fluid-cavities are present in this rock, varying much in size, and in some cases containing bubbles; these, it may be remarked, differ much in their size relative to the cavity, occupying sometimes from  $\cdot2$  to  $\cdot5$  of its whole volume. Some epidote, pyrite, hæmatite, and perhaps magnetite are present, with a kaolin-like mineral, probably replacing a felspathic constituent; the slide is traversed by cracks making a high angle with the lines of foliation, which are crumpled up near them, showing that the latter are due to a kind of cleavage subsequently produced. (6) A rather compact green schist from the headland just south of Polpeor (east side) has a general resemblance to (3), but contains less quartz and more of a granular earthy-brown mineral, probably replacing a felspar, which also occupies some transverse cracks. (7) A rather olive-brown mica-schist with silvery lustre, is a very pretty object under the microscope. It consists mainly of quartz and mica; the former in well-marked clear grains, cavities and inclusions being rare and minute. The mica occurs in wavy bands or divergent folia. Three kinds are present, brown, green, and colourless. The first is probably biotite; the second (often interbanded with it and containing



microliths of hæmatite and magnetite) an alteration-product from it; the third, which gives beautiful tints with crossing Nicols, rather resembles paragonite, and is no doubt one of the hydrous soda- or potash-micas. An earthy-looking granular felspathic constituent is occasionally present, as well as several small garnets. These are almost colourless, but often rather crowded with dirty-looking enclosures, and sometimes decomposed; a little kyanite (?) occurs.

(8) The lustrous greenish schist, at Porthalla, associated with the granitoid band (p. 8), consists mainly of a colourless mica, generally similar to that just described, with a fair amount of a green mineral, most of which resembles a mica, or possibly a chlorite, more than a hornblende. Quartz, sometimes certainly interstitial, is present in fair quantity, containing occasionally minute enclosures of the nature of which it is difficult to be certain. We note also some ferrite and impure epidote, sometimes in grains about .01 inch in diameter.

(9) Compact-looking schist, not far from the last (p. 8). This consists of films and belonites of green mica or hornblende with quartz, the last generally clear, occasionally with filmy pale brown microlithic enclosures: scales of hæmatite and, perhaps, some very small garnets are also present, with one or two grains which may be zircon; transverse cracks with infiltrations, as described above.

(10) The granitoid rock near the fault, Porthalla (p. 8). The slide consists of quartz, felspar, white mica, tourmaline, chlorite, with iron peroxide. The quartz frequently occurs in irregular patches of aggregated granules of variable size as in a quartzite; they contain microlithic enclosures of extreme smallness, often much less than .001 inch in diameter, many being cavities apparently empty. The felspar, often much decomposed, occurs sometimes in grains of very irregular outline up to about .3" diameter; orthoclase and oligoclase (?) are present. Of the tourmaline, which is not common, there are one or two crystals about the above size, the rest being microlithic. I note also a little cluster of garnets. The rock has evidently been crushed, which obliges one to be cautious in pronouncing on its structure; but I think we may safely regard it as a gneiss, not a vein-granite.

### B. *Hornblendic Group.*

The hornblende schist, of which I have had several slides prepared representing different varieties, is macroscopically a rock consisting of almost black hornblende, with more or less of a whitish felspathic mineral, quartz, and often yellowish epidote, the last sometimes occurring abundantly. The crystalline grains usually do not exceed about .05" in diameter. It varies from a massive rock, difficult to distinguish in hand-specimens from a diorite, to one distinctly foliated, finely banded, and obviously of stratified origin, sometimes even showing lenticular and still more minute current-bedding structures. Occasionally there is an approach to a porphyritic structure, denoted by the presence of eyes or spots of a



felspathic material. Examined microscopically, the hornblende generally is seen to be the most abundant material; the size of the crystalline grains varies from microliths up to (occasionally) .04" diameter; the former, however, are generally isolated among quartz, feldspar, &c. Where the hornblende occurs in patches the grains are of a moderate size. These are almost always rather irregular in outline, only the microliths exhibiting externally a crystalline form, but the characteristic cleavage parallel to  $\infty P$  is remarkably well developed. The usual colour is a sap-green; the mineral is strongly dichroic, changing from a deep tint of this to a straw-yellow. In some of the larger grains enclosures are common: these are of two kinds—one a filmy transparent mineral, apparently of the same colour with the surrounding material; the other a dark brown, almost opaque mineral, which sometimes assumes a prismatic form, at others is a mere dot; perhaps this is only an iron oxide; occasionally the crystal is full of these. Iron-glance of larger size, pyrite and magnetite are present; the feldspar grains are usually irregular in outline, and so far kaolinized that it is difficult to conjecture the species, sometimes, however, the striping of plagioclase is still visible. The epidote is granular in form, of a pale yellow colour, and generally gives brilliant tints with crossing Nicols. Well-characterized apatite is rare; sphene, or a mineral much resembling it, rather frequent.

I proceed to notice the microscopic structure of some of the varieties of this rock. A specimen of the normal dark schist, not markedly foliated, was described in my last paper; of those exhibiting more definite structures, we may take the following:—(1) Rock from Hot Point, with some indications of current-bedding and angular spots of whitish feldspar simulating fragments (p. 4), chiefly hornblende and feldspar, with some granules of an iron oxide and a little quartz, columnar microliths pale or colourless, some doubtless hornblende. Small grains and imperfectly formed crystals, sometimes aggregated, sometimes included in a hornblende crystal, of a very pale brown "granular-gummy"-looking mineral (if the term be permitted). Some almost certainly sphene; but of some all that I can ascertain is that the mineral is monoclinic or triclinic, and extinguishes at an angle of about  $15^\circ$  with its longer diameter. The larger grains of feldspar sometimes have their outline rather sharp, at others rather interlacing with the matrix. They are generally much kaolinized, but here and there the twinning of plagioclase is preserved, the angle between the direction of extinction of adjacent layers not exceeding  $15^\circ$ , so that it is probably albite. The same is exhibited by one or two of the better-preserved grains in the matrix. An indistinct irregular banding is visible in the slide. (2) Specimens of the dark schist with white "eyes" from Porthoustock (p. 8). Traces of foliation; minerals rather more aggregated than in the last; a little more quartz. Some microliths like those just described, but less numerous and paler in colour. A granular structure, as in a quartzite, rather marked in the transparent patches. Among the hornblende are occasional grains, nearly .05" diameter, having rather

a different aspect from the smaller ones, which contain numerous microlithic enclosures of opacite and of a nearly colourless mineral.

(3) Specimens of massive hornblende schist from near the fault in Polurrian Cove (p. 10). Minerals similar to those in No. 1, but the structure of the rock is a little coarser and more granitoid.

(4) Finely banded epidotic rock, Cadgwith Cove (p. 6). Hornblende, felspar (very decomposed), much epidote, and some quartz; separation of the minerals into layers very marked; sometimes epidote predominating. Microliths frequent, similar to those described above, fairly characteristic sphene, and a grain or two of pyrite. Cracks roughly transverse to bedding-planes, filled with a minute granular brownish mineral, like one which here and there replaces the felspar.

(5) White-banded hornblende schist, in Carnbarrow crags near sea to north of Dolor Hugo (p. 6). Structure similar to last, but little or no epidote, rock being chiefly hornblende and felspar.

(6) White-banded hornblende schist, almost touching serpentine on west side of mass, Porthalla Cove (p. 9). The felspar in this specimen is almost wholly replaced by granular brownish earthy minerals. The hornblende nearly colourless, similar in appearance to the "uralite" occurring in gabbros; a crack is filled with aragonite. The minerals in this rock have obviously been altered considerably since the period when they first crystallized; but there is no appearance whatever of a "passage" into the serpentine.

(7) Hornblende schist from crag just south of the termination of the serpentine, at the south end of Pentreath Beach. The minerals are in a condition very similar to those described in the last case, but the rock is a little coarser and more schistose in structure.

### C. *Granulitic Group.*

Two very common types of rock in this series, often inter-banded, and so producing the most conspicuously stratified portions, are the following:—one a rather finely granular pinkish-grey rock, composed mainly of quartz and felspar, with occasional specks of a dark mineral forming inconspicuous bands; the other a dark grey rock, in which the last-named mineral clearly predominates. Neither is conspicuously fissile, the former the less so. It exhibits almost every gradation, from a rock closely resembling a vein-granite to a rather felspathic quartzite. I have selected as types of the ordinary bands two specimens collected from the north side of the Frying Pan, Cadgwith (p. 6). Under the microscope, the first consists chiefly of grains of quartz and felspar, both being irregular in outline and variable in size, together with a dark mica and a little hornblende. The quartz contains in places minute filmy microliths and cavities, the latter varying considerably in size; but they cannot, as a rule, be examined unless magnified from 200 to 300 times at least. Bubbles are sometimes, but by no means universally, present. These certainly do not always occupy the same amount of the cavity: some-

times they are about  $\cdot 4$  of its whole volume, sometimes much less. The felspar is generally rather decomposed, but orthoclase and a closely twinned plagioclase (oligoclase or albite) can be distinguished. The mica is olive-coloured, associated with opacite, and is probably an altered biotite. There is, I believe, a little tourmaline, but it is not very characteristic. The dark rock consists of about equal quantities of felspar (mostly replaced by secondary microlithic products) and a rather platy green mineral, neither mineral having externally a definite crystalline form. There is also a little of a brown mica, epidote (?), ferrite, and opacite.

Taking now a specimen (collected from a mass caught up by the serpentine in the cliffs south of Poltesco, p. 6), in which the lighter and darker layers may be seen interbanded in a small hand-specimen (typical of much of the rock in the neighbourhood), we find the two varieties opposed in the slide. The passage between them is rapid, and their difference from those just described is only varietal. The quartz, however, contains numerous cavities, in many of which are bubbles, generally occupying a relatively small portion of the cavity. They seem often to be roughly arranged in lines nearly transverse to the general direction of the foliation, which here is rather more conspicuous than before. In one or two places is exhibited the curious micrographic structure, which has often been noted in metamorphic rocks, rudely resembling the canal-system structure of Eozoon. Another specimen, "from a little below the serpentine, near the arch in Polbarrow Cove, typical of much of the rock in the neighbourhood" (p. 5), exhibits a slightly closer and more irregular interbanding, as in a current-bedded rock. It contains less quartz in proportion to the felspar, and hornblende in all parts is more abundant than mica. The larger grains of the hornblende have their axes less uniformly parallel than in the former specimens, and parts of the slide come very near to some of those from the hornblende group. A still more remarkable specimen has been examined from Kennack Cove (p. 7, Pl. I. fig. 1). This, in a vertical thickness of about  $1\frac{1}{4}$ " , exhibits four light-coloured layers separated by dark bands; two of these are only about  $\cdot 1$ " thick, but another is nearly  $\cdot 5$ " , and in the upper part passes irregularly into the next layer. The materials of this appear to be mostly rather rounded grains of felspar, and one, about  $\frac{1}{4}$ " diameter, isolated in the neighbouring darker part, heightens the resemblance of the rock to an irregularly banded grit. The felspar occurs in grains very variable in size: the majority, rather less than  $\cdot 01$ " in diameter, form, with quartz, hornblende, and mica, a kind of ground-mass in which grains six or seven times the size, and sometimes much larger, are imbedded. The amount of decomposition is variable; some grains are excellently preserved; others, especially the larger, are quite kaolinized at the centre. The boundary between the decomposed interior and the undecomposed exterior band is often sharp. The former is rounded or subangular in form, the exterior of the grains (both in the small and in the large) being ragged and irregular, instead of straight-edged as in a porphyritic igneous rock. A closely twinned plagioclase



clase, apparently oligoclase, is very abundant; but I think that orthoclase is also present. The hornblende is of a pale green colour, moderately dichroic, with irregular outline and characteristic cleavage. The mica (in small flakes) is of a red-brown; some granules of an iron oxide are present. The largest (hæmatite?) encloses a small, imperfectly formed crystal of hornblende; microliths of hornblende and mica occasionally occur towards the edges of the larger felspar crystals, and various microliths, some probably needles of hornblende, others possibly apatite, occur in the ground-mass of the slide.

Specimens of the most granitic varieties of this series were described in my last paper (vol. xxxiii. p. 886), and I have examined a rather more compact specimen from a lenticular band near the W. headland at the Balk Bay; but in the case of this, except that the materials are more minute, the structure is so similar to the others that no additional description is needed.

The last to be described is a specimen of a rock underlying the projecting ridge on the rocky shore in Polbarrow Cove, whose weathered exterior much resembles an ordinary indurated felspathic and micaceous grit, an appearance which is not wholly lost on freshly broken surfaces. It consists of felspar, brown mica, and hornblende, with some quartz, the last generally in small grains and sometimes apparently interstitial. The description already given of the minerals will suffice; but the slide exhibits a more uniformly granular character than do the others.

#### *D. Remarks on the Structure of these Groups.*

I have discussed at some length the structure and mineral character of these rocks because they give rise, in my opinion, to some considerations which may prove to be of a little importance. Examination in the field and with the microscope fully justifies us in classing this last group as well as the others with the metamorphic rocks, and even among those which have undergone a very great amount of alteration. Many of the mica-schists in the lowest group, many of the hornblendic rocks in the middle one, and not a few of the granitoid bands in the upper are evidently highly crystalline. Their original structure has disappeared. It is a matter of conjecture what was the nature of the sediment of which they were formed, and to this their chemical composition alone can afford a clue. Yet occasionally, especially in parts of the middle and upper groups, we have the most minute phenomena of stratification clearly recorded by the mineral structure. It can hardly be doubted, I think, that such a rock as the banded epidotic hornblende schist of the headland in Cadgwith Cove, or that with the wonderful current-bedding at Hot Point, or such as those which abound in the upper group, has been the result of an original clastic structure. It seems, then, possible to me that in these and in some of the curiously banded rocks in the upper group many of the constituents may be in part original. I do not mean that any one grain as it now stands



is an original constituent ; crystallization *in situ*, especially in the case of the hornblende and mica, has taken place to a large extent. In the more minutely crystalline schist, the original structure is very probably wholly obliterated. Still, these larger felspar grains, for instance, may have as their nucleus felspar grains which were original constituents, and may have survived the dissolution of the finer sedimentary materials in which they were imbedded. Then in the process of reconstitution, felspar (not perhaps always of the same species) may have been added to felspar, quartz to quartz, mica to mica, and hornblende to hornblende or altered augite. Thus traces of the minuter structure of the original rock, even in a highly metamorphosed series, may now and then remain. In those beds where the chemical composition of the constituents facilitated change, or where the materials were finely levigated, the agents of metamorphism reduced the whole to a mere pulp (if the expression be permissible) from which the present mineral constituents crystallized, almost as they would do from the magma of an igneous rock ; but in other cases only a portion of the material was reduced to this condition, and those constituents which remained undigested would form nuclei around which the other minerals would crystallize, and would so continue to bear testimony to the original history of the rock itself. Thus the explanation of those granitoid bands, in some cases so curiously like granite veins, may be, that originally they were a rather coarse quartz-felspar grit. As regards some of the hornblende schists, one would suggest the possibility (as I believe has been elsewhere done by the late Prof. Jukes) of their having been basaltic tuffs, with which in chemical composition they would agree fairly well\*.

I have ventured on this digression because these Cornish rocks have presented structures which seem to me worthy of careful consideration by all who are studying the phenomena of metamorphism—a subject which has occupied my attention for some years past. The observations are not entirely novel. Dr. Sorby drew attention to somewhat similar structures in his very valuable and suggestive paper on the original constitution and subsequent alteration of mica-schist†. The agglutination of identical mineral matter has been noticed in the case of quartz by that author, by Mr. J. A. Phillips, and by myself, independently, not to mention others. In the gneissic series traversed by the upper part of the St. Gothard Pass, and in other districts, I have repeatedly noticed similar instances, all tending to show that the minute structures, and in some cases very probably the original constituents (at any rate as nuclei), may be preserved in rocks which are metamorphic in the fullest sense of the word.

\* See analysis by Mr. Hudleston in the Appendix to my former paper (vol. xxxiii. p. 924). While examining this hornblende group I had always present to my mind the possibility that the more massive varieties might be really metamorphic igneous rocks ; but I obtained no evidence in favour of this view, and am disposed to regard the group as, at any rate in the main, of sedimentary origin.

† Q. J. G. S. vol. xix. p. 401. See also many most suggestive and valuable remarks in his Presidential address, vol. xxxvi.

I trust some day to treat the subject more fully ; but I take this opportunity of calling attention to it, because I believe that in it we find a clue which may ultimately enable us to solve many difficulties in that most perplexing inquiry—the relation of the metamorphic and of the igneous rocks.

#### IV. *Age of the Metamorphic Series.*

A few words may be said in conclusion as to the probable age of this metamorphic series. In my former paper I called it “altered Devonian,” following the authority of others which I had then no reason for questioning. In this one I have adduced the reasons which have convinced me that it must be much more ancient. An immense interval of time separates its rocks from the slaty series found in juxtaposition. Even these deposits are not impossibly older than the Devonian series. According to Mr. J. H. Collins they are, at latest, Lower Silurian\*, and their general appearance would very well accord with such an age. We need not hesitate then to assign the metamorphic series to the Archæan Period ; and, so far as we can trust the evidence of mineral condition, we may refer them to no very late epoch in this. The amount of alteration in the Lizard sedimentary rocks is indeed less than we find in the more typical representatives of the Hebridean series of Scotland or of the Malvernian of England. It is only in the granitoid bands of the Upper Group (with one exception) that we are reminded of the Dimetian of St. Davids, or the most crystalline gneisses and “granitoidites” of Anglesey. But all these occur in thick masses, while those of Cornwall are in thin bands. In distinctness of bedding and in general mineral condition we may find parallels among some of the so-called Newer Gneisses in the Central Highlands of Scotland ; but, so far as I know, the latter the resemblances are not very close ; and in touching these we intrude upon a veritable “thistle-bed” of controversy, from which we would gladly keep clear. The closest resemblance known to me is between many members of the Micaceous Group and parts of a micaceous or chloritic series which is well developed in Anglesey, especially in Holyhead Island, on the adjacent coast, and on the northern border of the eastern part of the Menai Straits ; so that, without pressing the parallel too far, we may, I think, provisionally regard the Lizard rocks and these Anglesey schists as belonging to about the same age. The latter, I am aware, have been claimed by one author as altered Bala, an hypothesis which a petrologist can hardly believe to have been advanced seriously. By the Geological Survey they are regarded as altered Cambrian, a view which I think recent investigation has shown to be untenable. A third authority, while claiming them as Archæan, suggests that they are Pebidian.

\* See Trans. Roy. Geol. Soc. Cornwall, vol. x. pp. 5, 47, and Journ. R. I. Cornw. vol. vii. p. 18. He appears, however, to me to have completely mistaken the relation of the hornblende schist and serpentine one to another and to these rocks, and not to add any thing to the work of De la Beche, which he criticizes.

But if the Pebidians of St. Davids are to be taken as typical of that group, and if we are to put any trust at all in conclusions derived from lithological studies, we must assign a greater antiquity than this to these Anglesey rocks. Hence, as I consider that we are not yet in a position to offer a definite classification of the members of the Archæan series, I will say no more than that I consider these Lizard rocks to belong to some part, and that by no means the latest, of the record of that immense period of time.

#### V. *Further Notes on the Serpentine.*

I was obliged to leave two outlying patches of serpentine undescribed in my former paper on the Lizard district, but am now able to give some particulars concerning them. They are indicated on the Geological map, the smaller patch at Polkerris, the larger close to Porthalla. The former of these is best examined on the hill on the northern side of the cove, it being imperfectly, if at all, exposed on the shore. It is a compact variety, with a curd-like fracture, its colour varying from dull reddish brown to dark green, and is traversed by numerous joints (so that large specimens cannot be obtained) which are coated with steatitic films of green and red colour. A microscopic section exhibits the usual network structure of doubly refracting "strings," with an isotropic interior, which has been fully described in my former paper. We find the usual clustered granules of opacite, ferrite, &c., and one crystal, now replaced by serpentinous minerals, which I have no doubt has been bronzite.

The serpentine near Porthalla can be examined on the hill-side south of the cove and at the foot of the cliffs (at low tide). The junction with the hornblende schist was excellently shown at the time of my visit in a small quarry on the latter and in several places on the former. Though occasionally the compact nature of the schist, and the changes produced by weathering or by the secondary deposits of films of steatitic minerals, render the actual junction slightly obscure to the unaided eye, it can be detected in the field on closer examination, helped by the knife and hammer, and is indubitable when the microscope is used.

This serpentine varies from a dull purplish green to a greenish grey, the latter colour denoting the more weathered specimens. Sometimes it is a homogeneous dark rock, at other times it exhibits a very marked streaky aspect, reminding one of the fluidal structure of rhyolites. I have examined microscopically four varieties:— (1) from the compact dark serpentine, (2) from the grey-green one, (3) from a markedly banded specimen, (4) from a similar rock with small "eyes" of a filmy talcose mineral. The general character of the ground-mass resembles that of the last-described and of the more compact serpentines further south, the differences being only varietal. I consider the rock to be an altered peridotite, but to have been originally rather finely crystalline. No crystals of enstatite, hornblende, or augite are now recognizable; but some



clusters of opacite, associated with a colourless platy uniaxial or orthorhombic mineral (the whole from .01 to .02 inch diameter), may indicate the former presence of one or more of these; indeed, so far as I can judge from the traces of cleavage-planes, I should infer that a little enstatite, and possibly hornblende, had once been present. The banding is less conspicuous under the microscope than to the naked eye, but still is indicated by a general parallelism of the longer "strings," forming the meshes of the network, by an imperfect linear arrangement in the clustered granules of opacite, and by slight differences in the colour and mineral structure of the matrix, so that I regard it as a record of an original structure in the rock-mass\*.

In one place, at the base of the cliff, the serpentine exhibits a curious structure. Perpendicular to each joint-face cracks have formed about an inch deep, which have been filled up with whitish steatite, so as to exhibit a polygonal reticulation, the meshes being about half an inch in diameter. A fracture-surface shows a border, tolerably regular, of dull-coloured serpentine, divided by white lines. The inner mass is sometimes traversed by bands about  $\frac{1}{4}$  inch wide, with light edges and a dark inner stripe.

I may add that, in the course of my work, I reexamined almost all the junctions described in my former paper, and have no hesitation in affirming that there is abundant proof of the intrusive character of the serpentine in the Lizard district. Additional evidence, were it needed, was obtained in a quarry at Ynys Head, north of Cadgwith, where an exceptionally good section had been exposed, and in a small mass of serpentine (not previously noticed) in the hornblende schist to the north of Ugethawr, where the rotten serpentine is readily distinguished from the other rock, which it has broken through and disturbed. In short, I do not hesitate to say that if we have any evidence on which we can rely as proving the intrusion of an igneous into a sedimentary rock, we have it in the case of the Lizard serpentine and the metamorphic series with which it is associated. I mention this because some time since the following remark with reference to my former paper appeared in an article from the pen of Dr. Sterry Hunt, published in the (American) 'Annual Record of Science' for 1878, p. 293:—"When it is considered that there is abundant evidence that the North-American serpentines are indigenous, though often, like deposits of gypsum and of iron-ore, in lenticular masses; and, further, that the movements which the ancient strata have suffered have produced great crushings and displacements, it is not difficult to understand the deceptive appearance of intrusion which these rocks exhibit, and which are scarcely more remarkable than the accidents presented by coal-seams in some disturbed and contorted areas." I content

\* This is confirmed by the peculiarly compact condition of the serpentine in the narrow dyke on the shore north of Kynance (last paper, p. 920), at the junction at Ugethawr (*ibid.*), as well as in the cases described from Goonhilly Down, so that in these places the peridotite was probably in a glassy or very minutely crystalline condition (see Prof. Renard's paper, "Peridotit von der St. Paul's Insel im Atlantischen Ocean," *Neues Jahrbuch für Mineralogie*, 1879).



myself with remarking that Dr. Sterry Hunt has never seen the Lizard district.

The serpentines of the Lizard district afford us some varietal differences which, hereafter, on a more minute study than can be given by one who is only a visitor to the country, may possibly prove to be of importance. The handsome mottled varieties, with conspicuous crystals of bronzite, occur chiefly in the southern and south-eastern regions, along the coast from the Balk, near Landewednack, to Coverack Cove, and for a considerable distance inland, at any rate to the neighbourhood of Ruan Major, the fine black variety with glittering bronzite crystals being found on the coast south of Caerleon Cove; they occur also on the western coast some distance to the north of Kynance Cove (near the "Horse"). South of that, in the cove itself, and at the Rill, as well as to the north at Gue Graze, George Cove, and near Mullion Cove, compact dull-coloured varieties are commoner, and these are seen by the Helston road on the northern part of the mass. In close association with these is the dull-coloured variety, containing small glittering crystals, which appear to be mainly a pyroxenic or hornblendic mineral\*, found especially about Lower Pradanack and in Mullion Cove, but occurring locally also in one or two localities on the eastern coast about Dolor Hugo and the Frying Pan. A streaky structure is not seldom visible in these dull-coloured varieties, and this is especially conspicuous in the outlying mass at Porthalla, and in the more eastern part of the northern edge of the great mass on Goonhilly Downs (though here the rock is more highly coloured). I am distinctly of opinion, after reviewing all my specimens, that several of them, and notably the thin dykes at the foot of the crags north of Kynance Cove (vol. xxxiii. p. 920), have formerly been in a glassy or semicrystalline condition†.

The result of the above examination of the "Hornblende schist" shows that it can no longer be regarded as a metamorphic representative of Lower Devonian (or even Silurian) strata, but that it almost certainly belongs to some part of the Archæan series. As, then, the lower limit of the time during which the intrusion of the serpentine may have taken place is extended so enormously backwards, it seems at present hopeless to attempt to conjecture (as I did in my last paper) at what geological epoch this event may have happened, the only clue furnished us being that the serpentine on the western coast is cut by granite veins which are probably of the same age as the great masses further north, that is, later than a good part of the Carboniferous and earlier than the Trias.

\* In my former paper I called it augite, as it was practically colourless, and exhibited no dichroism. As it happened, none of the slides gave specimens with characteristic hornblende-cleavage. But I find the extinction-angles agree better with hornblende, and a specimen subsequently collected from near Lower Pradanack gives several transverse sections with indubitable hornblende-cleavage.

† See Prof. Renard, "Peridotit von der St. Paul's Insel im Atlantischen Ocean," Neues Jahrbuch, 1879. Also "Report on Petrology of St. Paul's," 'Challenger' Voyage (Narrative), vol. ii.

## EXPLANATION OF PLATE I.

Fig. 1. Specimen from the Granulitic Group in Kennack Cove (p. 17), showing interbanding of light and dark bands of different mineral composition, and an isolated rather fragmental-looking crystal of felspar.

Fig. 2. Specimen from the Hornblendic Group, Hot Point (p. 4), showing interbanding of layers with variable proportions of felspar and hornblende, having the appearance of current-bedding.

## DISCUSSION.

The PRESIDENT was unable to understand how any one who was acquainted with the sections could have the smallest doubt of the intrusive character of the serpentine of the Lizard.

The Rev. E. HILL remarked that the faulted condition of the metamorphic rocks was a natural result of their proximity to the intrusive boss of serpentine. He thought a rock in Sark, probably also of Archæan age, greatly resembled this hornblendic schist of Cornwall.

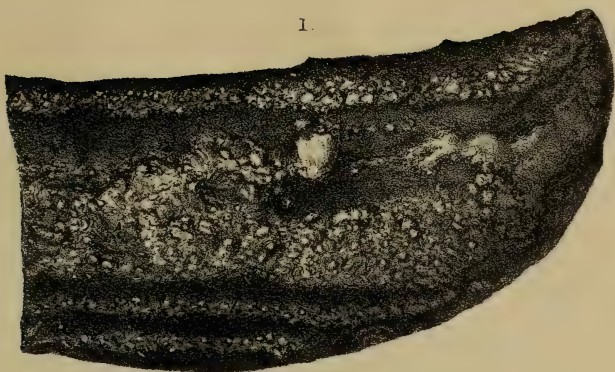
Mr. HUDLESTON stated that the hornblende schists have a very different composition from the schists at the S.W. angle of the Lizard Point. Some of the so-called hornblende schists greatly resemble a diorite, especially that at Penolver.

Dr. HICKS expressed his pleasure at finding these Cornish rocks recognized as pre-Cambrian. He had himself recently observed, in some new areas of Archæan rocks he had discovered in South Pembrokeshire, a hornblende schist which simulates the characters of a diorite. He believed the intrusive serpentines also to be of pre-Cambrian age. He remarked on the interest of Prof. Bonney's discovery of a conglomerate in the slate series containing pebbles of the rocks of the metamorphic series.

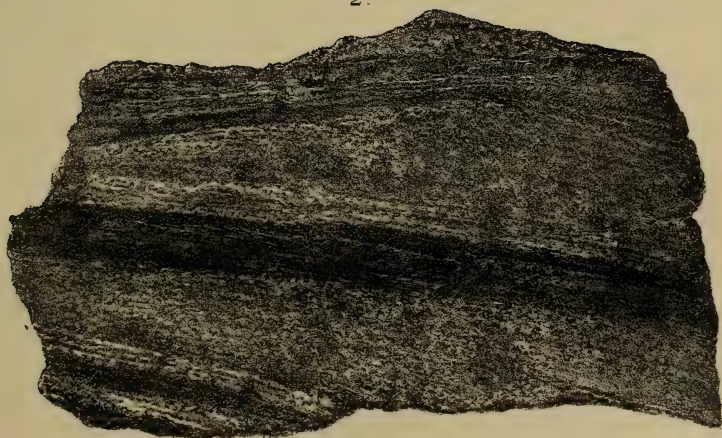
Mr. DREW asked for further information as to the grounds on which so small a thickness was assigned to the metamorphic series.

Prof. BONNEY, in reply to Mr. Hudleston, admitted that some of the hornblende schists closely resemble diorites, but that when studied in the field such varieties were found to graduate into ordinary hornblende schists. He could find no evidence (though he had expected it) of any of them being altered augitic lavas. He thought it wiser not to attempt to assign a definite place in the Archæan series to the Cornish metamorphic rocks. He did not believe that the metamorphism of the schists was due to the serpentine. In reply to Mr. Drew he said that he had not stated the series to be so thin as Mr. Drew supposed, still at some points there was clear evidence of the repetition of the beds by faults.

1.



2.







## 2. NOTES on some UPPER JURASSIC ASTORRHIZIDÆ and LITUOLIDÆ.

By Dr. RUDOLF HÄUSLER, F.G.S. &c. (Read November 1, 1882.)

[PLATES II. & III.]

THE latest researches on the arenaceous types of the Reticularian Rhizopoda from the Swiss Jurassic formation, especially from the zones of *Ammonites transversarius* and *A. bimammatus*, have yielded so many unexpected results concerning the relationship of certain species and varieties with recent forms, that a few preliminary notes on some important species may be of interest, as adding to the knowledge of the arenaceous Foraminifera in general, and giving new proofs of their wide geological range.

If we examine the various works on Swiss Jurassic Foraminifera, the small number of arenaceous forms recorded must surprise us. It may to some extent be attributed to the little attention which was formerly paid to many sandy species, and the imperfect knowledge of the simpler forms, but probably still more to the great difficulties attending a careful examination of the hard marls and limestones.

Most of the species are of comparatively small size and very fragile, whereby they easily escape observation.

The total number of determined arenaceous species is about 60 for the whole Swiss Jurassic formation, if we include the *Textulariide*; but, to judge from doubtful specimens and fragments, their number must become considerably greater by further researches.

These species, with an almost unlimited number of varieties, belong to the following genera:—

Psammospæra.	Placopsilinâ.
Astorrhiza.	Trochammina.
Rhabdammina.	Ammodiscus.
Marsipella.	Hormosina.
Hyperammina.	Webbina.
Lituola.	Thurammina.
Reophax.	Textularia (Plecanium).
Haplophragmium.	Bigenerina.
Haplostiche.	Valvulina.

By far the greatest number have been found in the lowest beds of the zone of *Ammonites transversarius*, from which all the specimens figured in this paper are taken.

While a few species are identical with Carboniferous or Permian forms (*Troch. (Am.) incerta, gordialis, pusilla, filum*), most of the others most nearly approach recent deep-sea varieties, from which they often differ but very little. The resemblance of the Rhizopodal fauna of the Jurassic "sponge-beds" to that of the deep sea is the more surprising, as many of the species have not been found in the younger formations.

As a more complete memoir on the Foraminifera of the zone of *Amm. transversarius* will appear next year, only a few species and

interesting varieties will be described and illustrated in this short paper.

*PSAMMOSPHERA FUSCA*, Schultze. Plate II. fig. 1.

There occur in the oldest beds of the Argovian stage, and again in the zone of *A. bimammatus*\*, minute spherical bodies of a coarsely arenaceous nature, without any large pseudopodial apertures, which agree in their principal characters with *Ps. fusca*, Schultze.

The cement is generally hyaline; but in a few cases a light yellow colour has been preserved. These spheres are very small, never exceeding 0.6 mm., and composed of large grains of quartz-sand. In the specimen figured, Pl. II. fig. 1, a part of the cement has been removed with dilute hydrochloric acid.

Before treatment with acids many arenaceous Foraminifera (*Psammosphæra*, *Reophax*, *Trochammina*, &c.) are very difficult to distinguish from grains of sand or fragments of other organic remains, as they are usually covered with a thin deposit of carbonate of lime.

*HYPERAMMINA VAGANS*, Brady. Plate II. figs. 2-6.

In the whole Middle and Upper Jurassic formation we meet frequently with the large, tubular, finely arenaceous tests of this species. Some free and attached forms have been erroneously described by me as purely siliceous and externally corroded organic remains†. The species is very variable as regards its external appearance, being entirely free, fixed, or partly free, straight, irregularly bent or twisted, sometimes spiral. The latter forms are always fixed. The simplest specimens form a large bulbous chamber drawn out in a long conical tube. *H. vagans* is the largest Jurassic Foraminifer, as it reaches a total length of several millimetres when attached to the stems of Crinoids, valves of Brachiopoda, &c.

From the recent forms described by Brady‡ they differ very little.

Though generally of pure white colour, specimens of a brownish colour are often met with.

*REOPHAX MULTILOCULARIS*, sp. nov.

Test long, slender, fragile, straight or irregularly bent, consisting of 22-25 small segments separated by slight constrictions. Oldest chambers broad, youngest oblong, rounded; test built up of comparatively large grains of sand, firmly cemented by a colourless calcareous cement. Surface very rough. Length 1 mm.

In its general outlines, *R. multilocularis* bears some resemblance

\* In a paper "Die Astrorhiziden und Lituoliden der Zone des *Ammonites bimammatus*," Neues Jahrb. f. Min. &c. 1883, vol. i., several species have been briefly described and figured, to show their identity with the forms from the older zone of *Amm. transversarius*.

† Häusler, Untersuch. über die micr. Struct. d. Aarg. Jurakalke, p. 25, pl. i. figs. 16, 20, 52-54.

‡ Brady, "Notes on some of the Reticularian Rhizopoda of the 'Challenger' Exp.," Micr. Journ. vol. xix. p. 14, pl. v. fig. 3.

to *R. nodulosa*, Brady, but the texture is sometimes like that of *R. scorpiurus*, Montf.

*R. multilocularis* appears to be characteristic of the Lower Malm of the Canton Aargau, where several specimens were obtained from a bed with numerous Cephalopoda.

REOPHAX HELVETICA, Häusl. Plate II. figs. 8-10.

This species was described by me as *Dentalina helvetica* \* from the zone of *Amm. transversarius*. It has since been found in the younger sponge-beds of the Swiss Malm †, but is nowhere common, and generally in small fragments.

REOPHAX SCORPIURUS, Montf. Plate II. fig. 7.

The figure represents a unilocular *Lituola*, which is probably identical with *R. scorpiurus*. The tests are generally of small size, seldom exceeding 0·8 mm., flask-like, somewhat pyriform, or long, cylindrical, often slightly constricted, or bent, of a coarsely arenaceous nature, and not rare in the sponge-beds of the lower Argovian étage. Small fragments of this or a nearly related species are common, but difficult to distinguish before treatment with acids.

There occur in the same beds other coarsely sandy tests of doubtful nature, which, owing to their bad state of preservation, often with chemical changes, could not be determined.

PLACOPSILINA CENOMANA, d'Orb. Plate III. fig. 1.

*P. cenomana* is one of the commonest arenaceous species of the whole Jurassic formation.

In certain banks of the Lower Malm it is almost impossible to find shells of Brachiopoda without traces of *Placopsilina* and *Hyperammina*. Typical specimens differ in no way from those of other formations.

THURAMMINA PAPILLATA, Brady. Plate III. figs. 2-6.

The Jurassic *Thurammina* differ but little from the recent forms described by Brady ‡. Some of the specimens still show the peculiar yellowish colour.

As the recent *Th. papillata* is very variable, we meet also in the *transversarius*-beds with a large number of varieties, passing from small, almost smooth, *Orbulina*-like forms to the large (1 mm.) papillated types.

In a few instances polythalamous specimens similar to that mentioned in Brady's paper were observed. As Uhlig § discovered the same species in the zone of *Amm. transversarius* in the neighbourhood of Brunn, *Th. papillata* must be a widely distributed species, mounting up into the zone of *Amm. bimammatus*.

\* Häusler, *l. c.* p. 34, pl. ii. fig. 45.

† Häusler, "Die Astorrhiziden &c.," Neues Jahrbuch f. Min. 1883, vol. i. p. 59, pl. iii. fig. 11.

‡ Brady, *l. c.* p. 26, pl. v. figs. 4-8.

§ Uhlig, "Ueber einige oberjurass. For. mit agglut. Sch.," Neues Jahrb. f. Min. 1882, vol. i. p. 152.

**THURAMMINA HEMISPHERICA**, Häusl. Plate III. figs. 7-9.

Test invariably fixed, nearly hemispherical, monothalamous, with few indistinct papillæ placed round the margin.

Test finely arenaceous, very thin, transparent. Diam. 0.5 mm. By its simple, more or less hemispherical chamber, the smallness and arrangement of the few papillæ, and the very thin, hyaline test this species is easily distinguished from the fixed varieties of *Th. papillata*.

*T. hemisphærica* is not common, but widely distributed in the zones of *Amm. transversarius* and *A. bimammatus*.

From these few notes we may conclude that probably most of the recent genera of Astrorhizidæ and Lituolidæ were already represented in Mesozoic sediments, either by the same or nearly allied species.

Though the zone of *Amm. transversarius* and chiefly its sponge-beds are the richest in arenaceous Foraminifera amongst the Upper Jurassic sediments, yet a careful study of the microscopic remains of the younger beds is sure to yield better results in time. Amongst these the zone of *Amm. bimammatus* (étage Séquanien I.) with a well-developed fauna of hexactinellid sponges is undoubtedly the richest; but the collecting offers great difficulties. A good many Astrorhizidæ and Lituolidæ were, however, collected about six years ago at Auenstein, Remigen, and the Rhyfluh.

From the zone of *Amm. tenuilobatus* about ten species are known from Baden and the Lägern. The English Upper Jurassic deposits seem to be much less rich in arenaceous Foraminifera.

The distribution within the limits of the zone of *Amm. transversarius* is very irregular, so that up to the present time certain species are known only from a small district or even a single locality, where the conditions for their preservation must have been specially favourable.

With the typical forms we meet in almost every zone with varieties or monstrosities from which many interesting facts concerning the relationship of widely different species may be obtained.

As a rule, we observe amongst the Jurassic Astrorhizidæ and Lituolidæ that all the hosts of varieties show a strongly marked tendency to fall back into the simplest typical forms, which, from their wide geological range, we are obliged to suppose possess the greatest chance of surviving in the struggle for existence.

## EXPLANATION OF THE PLATES.

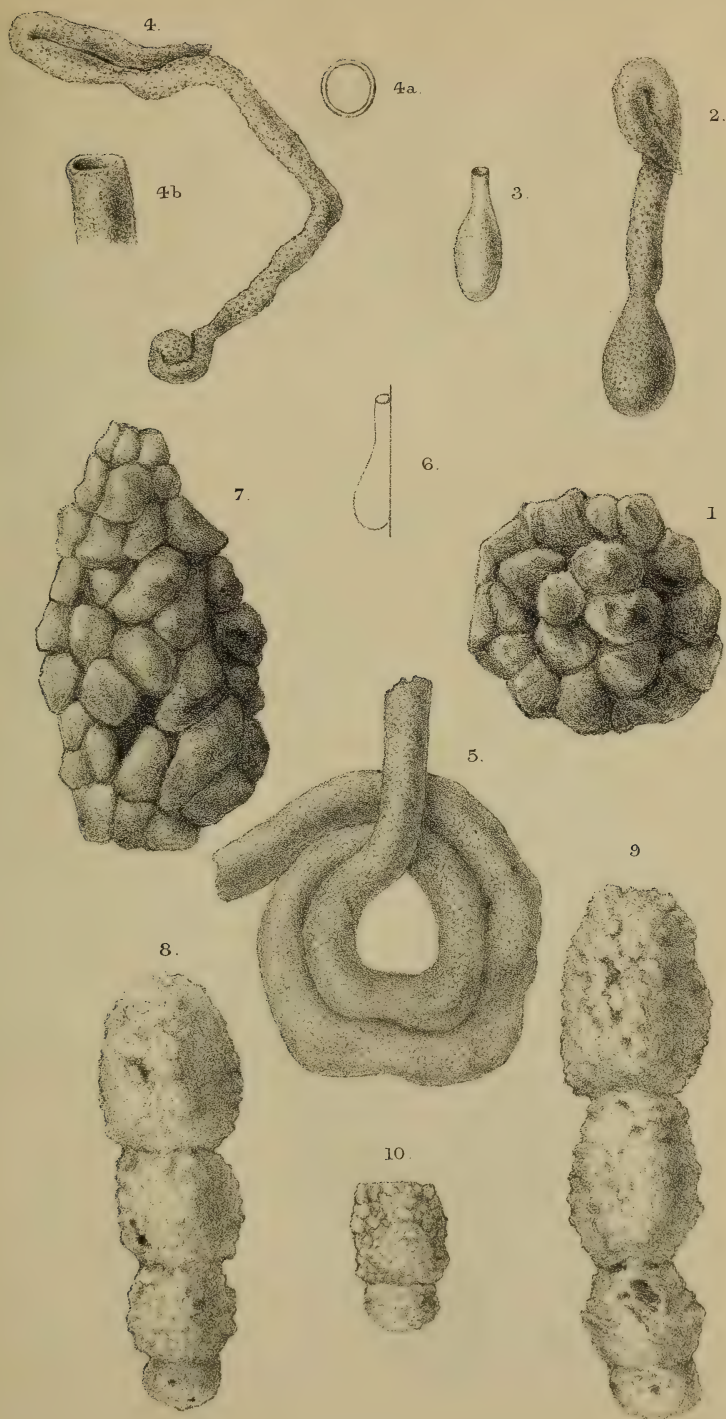
## PLATE II.

- Fig. 1. *Psammosphæra fusca*, Schultze.  
 2-6. *Hyperammina vagans*, Brady (spiral var.).  
 7. *Reophax scorpiurus*, Montf. (?).  
 8-10. *Reophax helvetica*, Häusl.

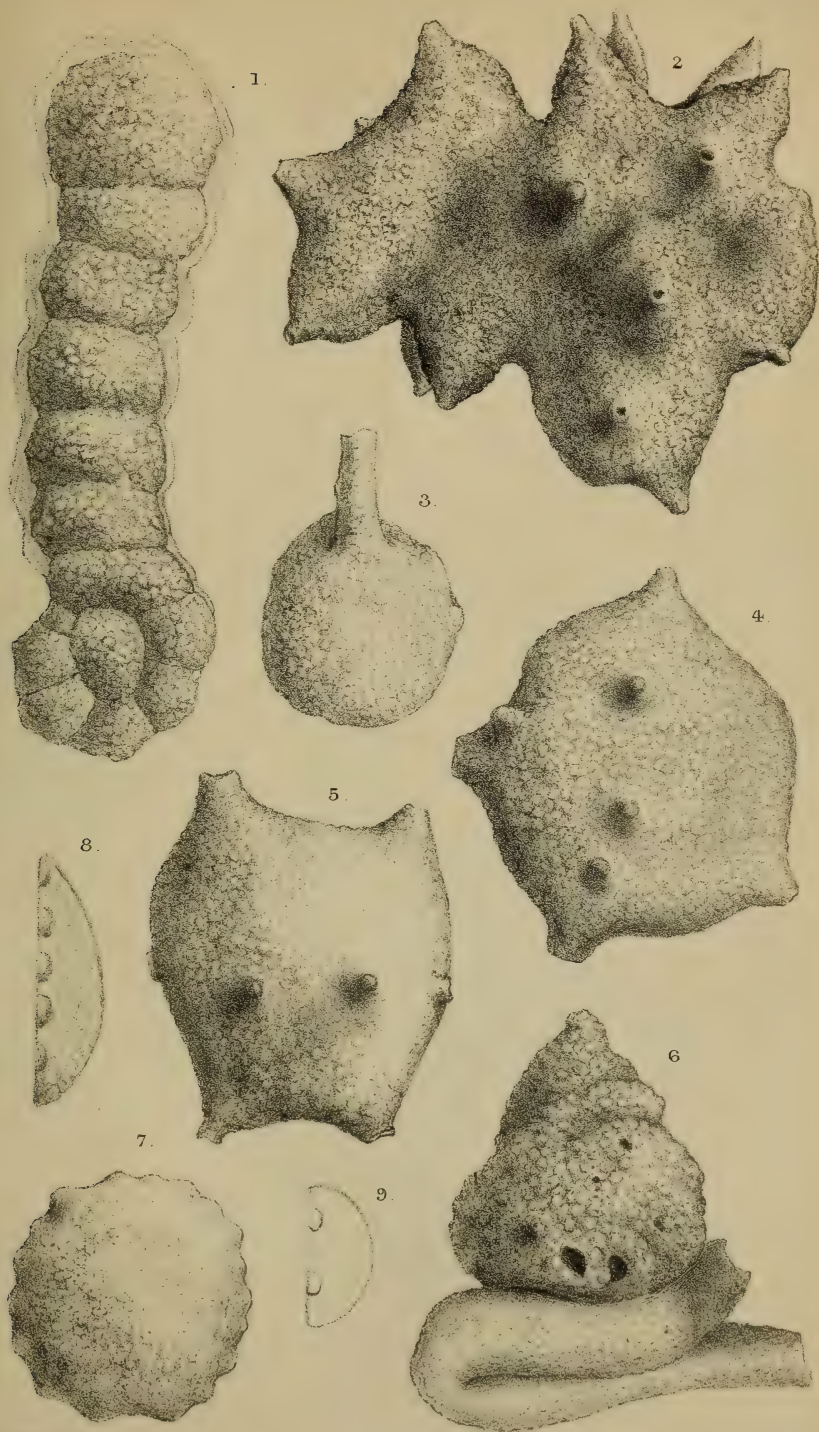
## PLATE III.

- Fig. 1. *Placopsilina cenomana*, d'Orb.  
 2-5. *Thurammina papillata*, Brady.  
 6. *Thurammina papillata* upon *Hyperammina vagans*.  
 7-9. *Thurammina hemisphærica*, sp. nov.













## DISCUSSION.

Prof. RUPERT JONES said that these deposits seemed to be of much interest. The difference of shape in Foraminifera was so great that it was not an easy task to settle the limits of a species. He described the mode of formation of the tests of arenaceous Foraminifera. The author had doubtless spent great pains in working out these Foraminifera. Arenaceous Foraminifera (Nodosarians) occur as far back as the Permian. The Society was indebted to Dr. Häusler for his important addition to our knowledge of the Swiss Foraminifera.

3. On *HELICOPORA*, a NEW SPIRAL GENUS (*with THREE SPECIES*) of NORTH-AMERICAN FENESTELLIDS. By Prof. E. W. CLAYPOLE, B.A., B.Sc. (Lond.), F.G.S., of the Second Geological Survey of Pennsylvania. (Read June 7, 1882.)

[PLATE IV.]

THE Silurian, Devonian, and Lower Carboniferous rocks of the Mississippi basin of the United States consist of thin limestones, and form altogether an insignificant mass when contrasted with the enormously thick deposits of the same age on the Atlantic border in Pennsylvania and the adjoining States, where the beds of corresponding age, composed for the most part of sandstones and shales, reach a thickness of from twenty to thirty thousand feet. Of these western limestones the Niagara group, the equivalent of the English Wenlock beds, has yielded a very rich harvest of fossil remains in almost all places where its beds are well exposed; but, being a typical dolomite, its fossils almost always occur as casts, the shells having been, except in very rare cases, removed by the percolation of acidulated water.

Among the fossils of the Niagara Limestone is a great abundance of fragments of various kinds of Polyzoa, especially of the family of Fenestellids, but in so broken and mutilated a condition that reference to species is impossible. Indeed there is room for believing that of the descriptions already published several may, in some cases, be founded on the same species.

During a residence of some years on the Niagara Limestone, at Yellow Springs, Green Co., Ohio, I obtained, among other Polyzoa, most of which were too imperfect for description, numerous specimens of a large and striking Fenestellid, quite distinct from every thing in the family already described, and yet showing features that fill an existing gap, and form a connecting link between two or three established genera. Before, however, proceeding with its description, it will be well to review in a few words our present knowledge of the American Fenestellids.

These beautiful fossils attracted attention very early in the history of palæontology, and were known as "Lace-Corals." The first to bestow on them a name was Miller of Bristol, whose name *Fenestella* was adopted by Lonsdale in 1839. His definition, as well as those of Phillips, McCoy, and King, was more or less unsatisfactory from want of precision or actual error\*; and the following definition has been given by Mr. G. W. Shrubsole, "after a careful study of the several species ranging from Silurian to Carboniferous times."

\* For details, see Mr. G. W. Shrubsole's paper on the Carboniferous Fenestellidæ, in Q. J. G. S. vol. xxxvii. p. 179.

“ Genus FENESTELLA, Lonsdale.

“ Polyzoary a calcareous reticulate expansion, either flat, conical, or cup-shaped, formed of slender bifurcating branches (interstices), poriferous on one face, connected by non-poriferous bars (dissepiments) forming an open network. Cells immersed in the interstices, and arranged in two longitudinal rows divided by a central keel, on which are often prominences. Cell-mouth small, circular, and prominent when preserved.”

Accepting this definition of *Fenestella*, it is highly probable that, when the day shall come for a thorough revision of the North-American Fenestellids, some of the 60 or more species at present standing under this name will be excluded or synonymized.

The closer and closer definition of the genus *Fenestella* has had the natural and necessary effect of excluding species after species, which have been placed in new genera or subgenera from time to time established. In this way the forms with a strong, stony, central shaft and spiral polyzoary have been set aside as *Archimedes*. *Polypora* includes those forms with more than two rows of true pores. Hall has grouped a number of species in which the expanded frond is stiffened by stony marginal arms on one or both edges as *Lyropora*. *Ptilopora* includes all forms possessing a stony midrib and foliate fenestrate fronds on each side. Thus those species which possess none of these characters remain in and compose the present genus *Fenestella*.

The following details in regard to the groups which have been successively separated from *Fenestella* will place their relations in a clearer light.

1839. *Fenestella*, Lonsdale and Miller. As defined by Lonsdale, this genus included the forms having three or more rows of cells, whether on the rays or the bars, such as *Polypora*, *Retepora*, &c. (Murch. Geol. of Russia, App. A, p. 629).

1842. *Archimedes*, Lesueur and D. D. Owen. No description was published with the figure on which this genus is based, and which appeared in the ‘ American Journal of Science and Art ’ for July 1842. Prof. Hall says, in the ‘ Palæontology of Iowa,’ p. 651, “ The Bryozoans designated as above by Lesueur do not differ in their essential structure from *Fenestella*; their mode of growth, however, is quite distinct, the flabelliform expansion acquiring a solid central axis, around which it revolves in an ascending spiral form, spreading equally in all directions.”

1844. *Ptilopora*, Scouler and M'Coy. “ Flabelliform or infundibuliform, attached by roots, from which a strong midrib arises, giving origin on each side to thin equidistant interstices, connected by regular dissepiments; external face of the interstices carinate, and bearing two rows of pores.” (Synopsis of Carb. Foss.)

1844. *Polypora*, M'Coy. “ Corallum forming a delicate, reticulated,

calcareous expansion, usually fan-shaped ; interstices round, having on one side from three to five rows of cell-openings, the margins usually not projecting ; interstices connected by thin, transverse, non-poriferous dissepiments ; reverse rounded, striated or granulated." (Synopsis of Carb. Foss. p. 206.)

1857. *Lyropora*, Hall. "Bryozoum consisting of foliate reticulated expansions, margined on either side by strong stony supports, which diverge from the base, curving outwards and upwards. The foliate expansion is spread out between these diverging arms, which are themselves formed by the coalescing and thickening of the branches." (Proc. Am. Assoc. Adv. Sci.)

It is scarcely necessary to add to this list *Ichthyorhachis* and *Glauconome*, McCoy, which are not fenestrate species, having no dissepiments\*.

There may be difference of opinion concerning the value of these groups, but most of them are now regarded by American geologists as genera. The discovery of species yet unknown may in the future unite one or more of them with others ; but for the present their limitations are sufficiently distinct for palæontological purposes.

The three fossils which form the subject of this paper show characters which place them in strictness outside of all the genera above enumerated. Further considerations on this point will follow presently. I therefore propose to place them by themselves in a new genus of Fenestrellids, defined for the purpose as follows :—

#### HELICOPORA, n. g.

Polyzoary expanded, fenestrate, and spiral, formed of slender bifurcating rays, poriferous on one face, connected by non-poriferous bars, forming an open network ; cells arranged in two rows along the rays, one row on each side of a median keel. Axis none, or consisting only of the thickened inner border of the polyzoary, not straight, but forming a spiral rounded non-poriferous or slightly poriferous inner margin.

*HELICOPORA LATISPIRALIS*, n. sp. Plate IV. figs. 1, 1a.

*Sp. char.* Polyzoary very widely expanded, sometimes as much as eight inches in diameter, very flat, curving downwards towards the centre as into a funnel. Whorls about half an inch apart, dextral or sinistral. Rays about fifty (40–50) in an inch ; fenestrules about twenty-five (22–28) in an inch in length, and from forty to fifty in an inch in breadth, according to the number of rays. Central axis or shaft *very thin* or entirely absent, and indicated only by a very slight thickening of the inner margin of the polyzoary. Outer or lower surface poriferous. Rays keeled.

\* It may be worth while to point out here the misuse of the word "interstice" in many descriptions of Polyzoa. This term properly signified a space or interval, and not its boundary. It should consequently, if used at all, be applied to the fenestrules, and neither to the rays nor the bars (dissepiments). It would be as well to avoid the use of the term altogether.



The above description was drawn up from an examination of several (6 or 8) specimens.

*Horizon and locality.* Upper beds of the Niagara (Wenlock) group of the Upper Silurian at Cedarville, Greene Co., Ohio.

Name derived from the spiral form and breadth of the polyzoary.

The place where these specimens occur is at an outcrop of the Upper Silurian rocks on the eastern slope of the Cincinnati arch, a flexure in the strata, dating probably from late Cambro-Silurian times. The beds of that formation there exposed are considered nearly equivalent to the Guelph beds of Sir William Logan in Canada. The fossils occur only in one layer in the quarry, and often in nests. Very frequently, even in the same bed, none can be found, their occurrence being extremely local and uncertain. In some of the specimens four complete whorls of the spiral polyzoary may be easily counted, separated from one another by about half an inch of stone.

The Corniferous Limestone of the Mississippi basin (Lower Devonian) is one of the most fruitful fields for the palæontologist. Not only are fossils abundant on numerous horizons, but they are often preserved with a perfection that brings out their minutest details of structure. As its name implies, this group abounds in flint, the silicified organisms of former times; and even where purely calcareous, as at the Falls of the Ohio, its Corals and Polyzoa cannot be surpassed or equalled for beauty, unless it be in the localities to be next mentioned. Accordingly the specimen about to be described is not subject to the objections mentioned in the last description.

# HELICOPORA ULRICHI, n. sp. Plate IV. fig. 2.

*Sp. char.* Polyzoary a thin spiral sheet of calcareous material, somewhat thickened towards the base, the lowest part of which is unknown, rising so as to make one turn of the spiral in an inch. The frond makes an angle of about  $35^{\circ}$  with the imaginary axial line in its lower portion. The angle is somewhat greater toward the circumference, owing to a slight droop of the expanded sheet of the polyzoary in its outer and thinner portion. Expanse of polyzoary unknown, but not probably exceeding an inch or two inches. Axial edge considerably thickened and rounded, poriferous, but without fenestrules.

Inner face poriferous.

Rays straight, ridged on the inner or front face, 50 in an inch, not visibly striated, but striæ may have been originally present; smooth and rounded on the outer or back surface, not ridged or striated.

Dissepiments or bars, on the front face rather lower than the rays, and broader at their junction with them; on the back of equal height, and the rays smooth and rounded like them.

Fenestrules 36 in an inch in length, but variable in size, not extending through the polyzoary near the axial edge, and entirely absent for about  $\frac{1}{10}$  of an inch from that line; oval in front, at

back nearly round, and towards the axial edge represented by narrow false fenestrules, some of which measure  $\frac{1}{10}$  of an inch in length, retaining the usual width.

Pores circular, usually three, often four, on each side of a fenestrule, distant about their own diameter; the highest and lowest are often situated in the angle between the ray and the dissepiment.

*Horizon and locality.* The Upper Helderberg or Corniferous Limestone, at the Falls of the Ohio, near Louisville, Kentucky. It was found by Mr. E. O. Ulrich, of Cincinnati, after whom I have consequently named the species.

This species is exceedingly different in appearance from *H. latispiralis*, in consequence of its small size, the nearly upright position of the spiral expanded polyzoary, and the rapid ascent of the spiral; but it agrees with that species in all its generic characters, absence of axis, and spiral growth.

It is an exceedingly beautiful little species, of which, however, I know no other specimen than that here described; but this is so well preserved that little or nothing remains to be desired for completing the specific description of all the parts that are present.

This fossil is interesting, as it shows the continuance of the spiral form from the Silurian (Niagara) system, in which *H. latispiralis* occurs, into the Devonian, not apparently as a deformity or sport, but as a normal habit of growth. Its minuteness is striking compared with the comparatively enormous size of its Silurian predecessor. This is plainly shown in the figures, where, though enlarged to double its actual size, it looks but a pigmy beside the larger and older species.

The Lower Carboniferous Limestone of the Mississippi basin, from which the species next to be described was obtained, equals or, if possible, in some respects surpasses the Corniferous Limestone in the quantity and beauty of its organic remains, especially Crinoids and Polyzoa. Its fossils, too, are equally well preserved. The fineness of the material has moulded their minutest details of structure, and the absence of acidulated water has prevented their destruction or incrustation.

HELICOPORA ARCHIMEDIFORMIS, n. sp. Plate IV. figs. 3, 4.

*Sp. char.* Polyzoary a thin calcareous spiral sheet, very much thickened at the basal or axial portion, rising so as to form one turn of the spiral in an inch, and making with the imaginary axial line an angle of about  $35^\circ$ . Expansion of the polyzoary unknown, but probably not large. Only two small fragments of the thin and expanded portion are preserved in the only specimen known to me, from which this description is compiled.

Lower or inner edge of the polyzoary considerably thickened, and forming a distinct rounded edge. It does not, however, form an axis, but itself runs up spirally round the place where a solid axis would be if it were present. It measures one tenth of an inch in thickness, and is finely striated longitudinally.

Outer surface poriferous.

Rays straight, 50 in an inch; outer or front face not visibly ridged or keeled, inner face concealed in the matrix.

Dissepiments on front face rounded, of equal height with the rays, but rather narrower, widening toward the junction; inner face concealed.

Fenestrules 40 in an inch, varying somewhat in size. Towards the base not extending through the polyzoary, and gradually disappearing toward the axial edge; outer face oval, inner face concealed.

Pores circular, usually three on each side of a fenestrule, rather more than their own diameter distant from one another.

The above description of the rays, dissepiments, and fenestrules must be regarded as relating to the lowest portion of the polyzoary, which alone is preserved in the specimen described.

It was found at Litchfield, Kentucky, by Mr. E. O. Ulrich, of Cincinnati, in beds of Lower Carboniferous age—the Kaskaskia group or Upper Archimedes Limestone.

This species, *H. archimediiformis*, forms a very interesting term in the series here described. Of nearly the same size as *H. Ulrichi*, it yet shows a marked advance towards the forms with a strong straight axis which constitute the genus *Archimedes* of Lesueur. In *H. latispiralis*, of the Upper Silurian (Niagara group), scarcely the slightest trace of an axis or even of any thickening of the inner border of the polyzoary can be discovered, but the foliate portion is enormously expanded. In *H. Ulrichi*, from the Lower Devonian, the inner edge is considerably thickened, but does not constitute any thing resembling an axis. In *H. archimediiformis*, from the Lower Carboniferous, the inner edge of the spiral polyzoary is so thick that it approaches somewhat in appearance to an axis, and were it straight might fairly be regarded as such. Centralization, so to speak, had made considerable progress since Silurian days.

The three species here described prove the continuation of the spiral type of Polyzoon into the Carboniferous, and not its origination there. Two horizons in that system in America have been hitherto the exclusive geological home of the spiral Fenestrellids. The Lower Archimedes Limestone or the Keokuk and Warsaw group has yielded

*Archimedes Owenanus*, Hall,  
*A. reversus*, Hall,  
*A. Wortheni*, Hall

(if, indeed, *A. reversus* be entitled to the rank of a species); and the Upper Archimedes Limestone or Kaskaskia group has yielded

*Archimedes laxus*, Hall,  
*A. Meekanus*, Hall,  
*A. Swallowanus*, Hall.

These six (five?) species are all that have been hitherto described, the genus being at present strictly limited to these two horizons.

It may appear to some, from the drawing, that the last of the three species here described, *H. archimediiformis*, might be almost



as truly referred to the genus *Archimedes*. Nor would the impression be unwarranted; but a comparison of the fossil itself with an *Archimedes* brings out the distinctions more clearly than they can be shown in a figure. Moreover, since the spiral form of polyzoary is found outside of the genus *Archimedes*, it can no longer be held as an essential characteristic of that genus. *Archimedes* must therefore be characterized by the spiral polyzoary in connexion with the axis; and in all the hitherto known species of that genus this axis is strong and straight, forming a true central line. Consequently the distinction between *Archimedes* and *Helicopora archimediiformis* is easily seen.

Were the difference, however, less obvious, the reference to *Helicopora* would not necessarily be incorrect. As palæontology advances, we continually find new forms filling the gaps previously existing between others already known; and such connecting links may in many cases be referred with justice to either of the two genera which they connect. Such cases are constantly occurring, and must be expected to occur yet more frequently in the future\*. In the present instance it is evident that the spiral mode of growth was not uncommon among the older Fenestellids, and cannot therefore be regarded as a mere "sport." Its range at present is from the Upper Silurian to the Lower Carboniferous. The large size of *H. latispiralis* forbids our supposing that it was the first of the kind, and it would be extremely rash to assume that the Kaskaskia species were the last. We may reasonably anticipate the discovery of other forms which will connect by closer links those already known, and perhaps establish a series from beds older than the Silurian to beds newer than the Carboniferous.

On the larger question whether or not all these groups should be thrown together again as *Fenestella*, this is not the place to enter: the numerous distinct forms found in the North-American Palæozoic rocks would make such a discussion both difficult and unsatisfactory in the present state of our knowledge. There are more than sixty species already described under the generic or subgeneric names quoted above; and to whatever extent these may be hereafter reduced, enough would still remain to render the retention of the present term very advantageous.

\* In this connexion the following extract from Mr. G. W. Shrubsole's recent paper on the "British Upper Silurian Fenestellidæ," will be valuable as confirmatory evidence:—

"As to the question whether *Fenestella intermedia*, with its three rows of pores, ought also to be included with *Polypora*, it may fairly be left open for consideration. . . . It may be, and is, difficult in practice to draw the line as to where *Fenestella* ends and *Polypora* begins. The genus *Polypora* was founded by Prof. McCoy for that division of the *Fenestella* family having more than two rows of cells on the interstice; the usual number of rows of cells in *Polypora* is from three to ten. These intermediate or compound forms, as *Polypora incepta* or *Fenestella intermedia*, were then unknown, and the difficulty as to classification had not arisen. *Fenestella intermedia* is clearly one of those connecting links between allied genera which, while they serve to unite the family as a group, are somewhat difficult to classify."—Q. J. G. S. vol. xxxvi. p. 251.



The discovery of other spiral Fenestellids is rendered more probable, indeed almost certain, by the early date of the first species here described. This form has been hitherto sharply limited to one horizon, that of the Keokuk, Warsaw, and Kaskaskia limestones in the Lower Carboniferous. The occurrence of *H. latispinalis* in Silurian rocks gives us the prospect of finding in the intervening Devonian beds, which in N. America have not yet been well searched, species additional to the single one described above from the Corniferous Limestone.

It may serve to place the relations of the groups of fossils to which allusion has been made in a clearer light if they are arranged in a tabular form, thus:—

Pores arranged in two rows.

Polyzoary not fenestrate:

Polyzoary irregularly branched..... *Galuconome*.

Polyzoary plumose ..... *Ichthyorhachis*.

Polyzoary fenestrate.

Polyzoary spiral :

With a straight central axis..... *Archimedes*.

Without a straight central axis..... *Helicopora*.

Polyzoary not spiral :

Polyzoary with strong midrib ..... *Ptilopora*.

Polyzoary with strong lateral ribs ..... *Lycopora*.

Polyzoary without ribs ..... *Fenestella* (proper).

It will be seen that the only ground of subdivision among the fenestrate group is the mode of growth. By referring to the definition given at the beginning of the paper the details of this structure may be seen.

Prof. Hall writes (Proc. Amer. Assoc. Adv. Sci. 1856, p. 177):—"In all the essential characteristics the foliate expansions of *Archimedes* correspond to *Fenestella*, according to the extended description of this genus by Mr. Lonsdale; and in detached fragments cannot be distinguished generically from other forms of the same genus." And further, in the 'Palæontology of Iowa' (p. 651):—"Their mode of growth, however, is quite distinct; the flabelliform expansion acquiring a solid central axis, around which it revolves in an ascending spiral form, spreading equally on every side."

This is equally true of the two coordinate groups (whether genera or subgenera matters little) *Ptilopora* and *Lycopora*, and in a less degree of *Fenestella* (pr.), inasmuch as it is characterized by negative features, if the expression may be allowed. The mode of growth, then, in this family is evidently admitted as a principle of subdivision, and it would be difficult or impossible to obtain any other. No Fenestellid of spiral growth has yet been described without the axis of *Archimedes*, and no *Archimedes* without this strong, straight central shaft, and almost always stony braces between the whorls. Consequently *Helicopora* takes up ground hitherto unoccupied, filling a gap and supplying a connecting link between *Fenestella* and *Archimedes*.

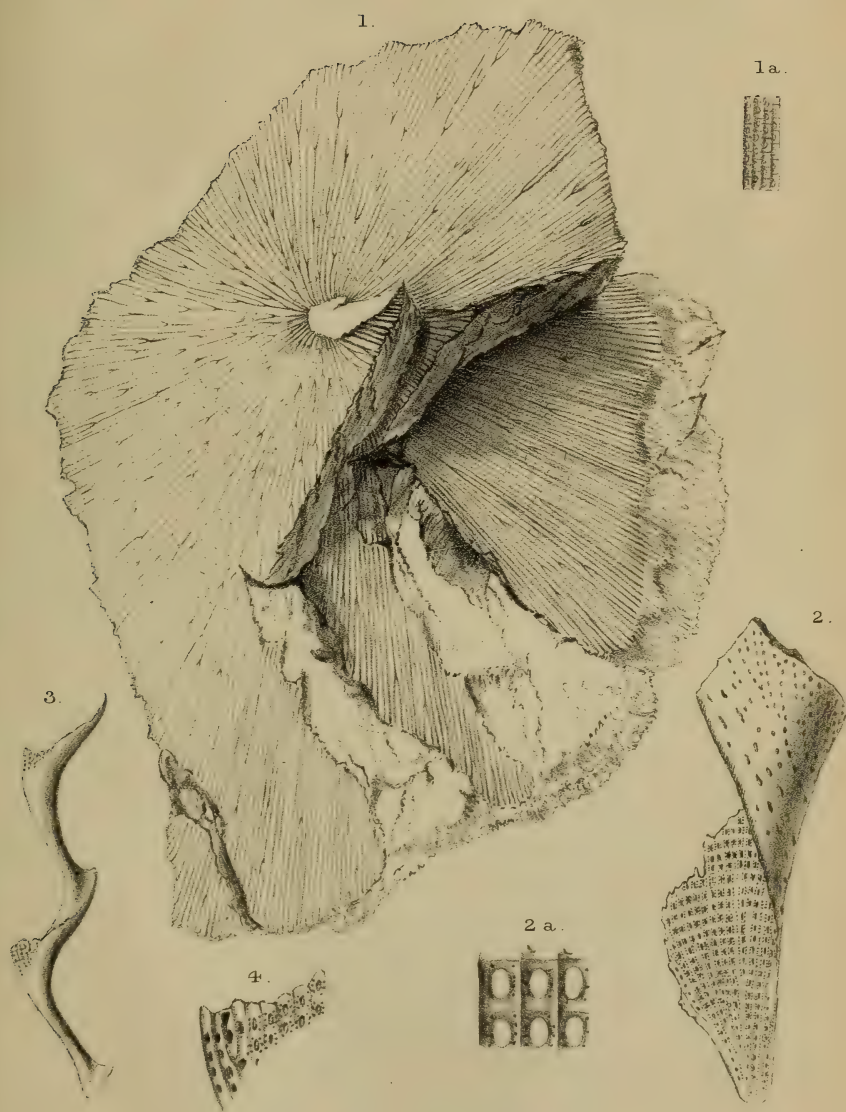
It is, in conclusion, worthy of remark that the Old World has not contributed any spiral Polyzoan to the catalogue, unless it be

as an occasional "sport," or *lusus naturee*. Possibly such forms may yet be found in imperfectly known districts; but it is almost idle to expect them from rocks so well searched and so long studied as the Mountain Limestone of England. Meanwhile these beautiful fossils form an exceedingly interesting example of local development, and supply an argument of some weight in favour of the separation of the inland basin of North America from that of Europe, either by physical barriers or impassable conditions during the period of their rise, culmination, and decay.

NOTE. *September 18, 1882.*—Since the above paper was written, Prof. James Hall has described in a small pamphlet sixty-three species of *Fenestella* and *Polypora* from the Upper Helderberg and Hamilton groups of the Devonian in the United States. Of these sixty-three species, forty are infundibuliform, one cup-shaped, one flabellate, and twenty-one indeterminate. Not one of them is spiral.

#### EXPLANATION OF PLATE IV.

- Fig. 1. *Helicopora latispiralis*, lower face, showing four whorls of the spiral, nat. size. *a.* A small portion enlarged 2 diameters.  
 2. — *Ulrichi*, enlarged 2 diameters. *a.* A small portion enlarged 8 diameters.  
 3. — *archimedisformis*, nat. size,  
 4. Enlarged view of a poriferous part of fig. 3, magnified 4 diameters.



A. S. Foord. lith.

Mintern Bros. imp.

HELICOPORA.





4. *On the EVIDENCE of GLACIAL ACTION in SOUTH BRECKNOCKSHIRE and EAST GLAMORGANSHIRE.* By J. W. EDGEWORTH DAVID, Esq.  
Communicated by Prof. J. PRESTWICH, F.G.S. (Read November 15, 1882.)

1. *Introductory.*

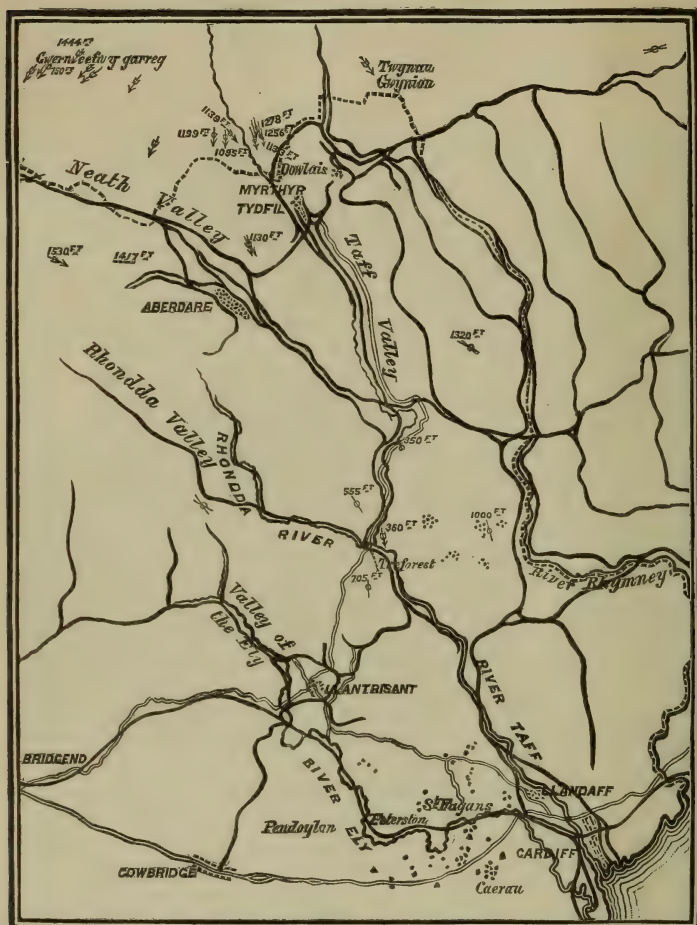
EVIDENCES of glacial action seem to have been very little studied hitherto in this part of South Wales. Professor Ramsay, in the fifth edition of his 'Physical Geology and Geography of Great Britain,' merely mentions the occurrence of ice-scratched erratics all along the low ground of Glamorganshire north of the Bristol Channel, between Cardiff and Bridgend, and says that Boulder-clay is common here and there all over South Wales. Mr. A. Tylor has described glacial markings on the surface-rock at Hirwain Common, near Myrthyr Tydfil\*. No one, however, so far as the author is aware, has as yet attempted to work out the problems of these glacial phenomena in a connected manner. And yet few parts of Great Britain offer equal facilities for such a study. This is chiefly owing to the great development in South Wales of rocks so favourable to retaining marks of glaciation as the Millstone Grit and Pennant Rock, and to the fact that the length of their area is more or less transverse to the direction of glaciation. The Millstone Grit, cropping out to the north of the South-Welsh coalfield, runs east and west, without interruption, except at Caermarthen Bay, from  $1\frac{1}{2}$  mile S.W. of Abergavenny, in Monmouthshire, to within 2 miles of St. Bride's Bay, in Pembrokeshire. This band of Millstone Grit, 76 miles long, and from  $\frac{1}{4}$  mile to 2 miles in breadth, probably shows glacial markings at intervals throughout the greater part of its length. In Brecknockshire, even where it must have been exposed for ages to subaerial waste, it still presents a polished and striated surface.

The Pennant Rock and sandstones of the Coal-measures often exhibit grooves and striæ when their surface is protected by a thin covering of turf or rubble; striæ may also be preserved in places on the surface of the Millstone Grit at its southern outcrop, though they are here unknown to the author. A careful examination of such an extensive glaciated area might serve to connect the glaciers of North and South Wales, while some light might be thrown on the question of the supposed extension of the Scandinavian ice-sheet into the Bristol Channel if glacial striæ could be discovered on the Millstone Grit or Carboniferous sandstones of the Forest-of-Dean or Bristol coalfields. Being unable, owing to an appointment abroad, to continue such an investigation, the author communicates to the Society the results of his work, though very incomplete, hoping they may be of some use to future workers in the same field.

The area embraced in this paper (see Map, p. 40) extends north and south from the Brecknockshire Beacons to a line drawn between Cowbridge and the mouth of the river Rhymney, and east and west

\* Quart. Journ. Geol. Soc. vol. xxiv.

Fig. 1.—Sketch Map of South Brecknockshire and East Glamorgan-shire. (Scale,  $\frac{1}{6}$  inch to 1 mile.)



from the Rhymney and Taff-fêchan valleys to a line drawn from Cowbridge to Ystrad-fellte, in the Neath valley. Its extent is about 200 square miles; but only a small part of it, viz. the Ely valley below Llantrisant, has been examined by the author at all thoroughly.

## 2. Surface-Phenomena.

There are six principal kinds of evidence of glacial action in this area:—1. Erratics; 2. Boulder-clay; 3. Polished, smoothed, shattered and contorted rock-surfaces; 4. Grooved and striated rock-surfaces; 5. Glaciated contour of country; 6. Contorted bedding in drift.

The whole of this area has a *moutonnée* aspect: the outlines of nearly all the hills are smooth and flowing, while drums, sow-backs, and troughs are noticeable features, especially on the south side of the Ely valley. *Roches moutonnées* are of frequent occurrence in Brecknockshire, in the Old Red Sandstone, Carboniferous Limestone, and Millstone-Grit areas, but are rarely met with in the Coal-basin or Ely valley; they are fairly well developed, however, on the Carboniferous sandstone at the top of the Avon Dare valley, near Aberdare, on the Millstone Grit at Cefn Hirgred, near Bridgend, and on the Lower Lias limestone at St. Fagans, near Cardiff. Contorted bedding in drift is well shown in the cutting on a new line of railway at Craigau, near Llantrisant.

The four other kinds of evidence must be described in detail. These are:—1. Erratics; 2. Boulder-clay; 3. Shattered and contorted rock-surfaces; 4. Grooved and striated rock-surfaces. The first three obtain everywhere in this area, whereas grooved and striated rock-surfaces are confined, so far as the author is aware, to the sandstones of the coal-basin, north of Maendu, near Treforest in the Taff valley, to the Millstone Grit at its northern outcrop from the Coal-measures, and to a small extent of Carboniferous Limestone cropping out to the north of this Millstone Grit.

1. *Erratics*.—All the erratics are of local origin, with the exception perhaps of the chalk flints of the Ely valley, and possibly of a small block of quartz-porphry found in an old wall at Duffryn Golwg, St. Nicholas, Cardiff.

The area of their dispersal extends 29 miles from the Beacons to the southern water-parting of the Ely valley, between Cardiff and Cowbridge, very few erratics occurring south of this watershed. Eastward they have been traced by the author to the Rhymney and Taff-fêchan valleys, and westward to a line drawn from Cowbridge to Ystrad-fellte, in the Neath valley. Thus the erratic area forms a wedge-shaped tract of country, 8 miles broad at its northern, and 15 miles at its southern limit.

The erratics are composed of angular, subangular, and rounded blocks of Old Red Sandstone, Carboniferous Limestone, Millstone Grit, Carboniferous sandstone, and Cockshot as far south as the Coal-measures. South of this line they are found associated with boulders derived from the Triassic and Liassic formations, and with sub-angular fragments of Chalk flints.

The greatest height of the Old Red Sandstone erratics above the sea-level is from 1400 to 1500 feet; that of the boulders derived from the Carboniferous Limestone and Millstone Grit from 1200 to 1300 feet; that of the erratics of Cockshot and Carboniferous sandstone from 700 to 800 feet. In the Ely valley boulders derived from the Trias and Lias seldom occur higher than 300 feet above the sea-level. Erratics derived from all these formations are to be found in the Ely valley as low as within 50 feet of the sea-level.

The area of the dispersal of the erratics, north of the southern outcrop of the Coal-measures, may be conveniently divided into two



districts, the Glamorganshire and the Brecknockshire, according as the erratics in each area were dispersed by Brecknockshire or Glamorganshire rocks. As the erratics of the Ely valley east of Peterston have been derived partly in Glamorganshire and partly in Brecknockshire, the area occupied by them and the few foreign(?) erratics of Chalk flints and one of quartz-porphry may be termed "mixed."

*Brecknockshire Erratic district.*—The district in which the erratics are nearly all derived from Brecknockshire rocks extends from the Beacons, twenty miles south, to the Eglwysilan mountain, and east and west from the Taff-fêchan and Rhymney valleys to the Neath valley, as far south as Glyn Neath, and the Aberdare valley and the left side of the Taff valley as far south as Walnut-tree Bridge. These erratics consist of blocks of Old Red Sandstone, Carboniferous Limestone, and Millstone Grit. The bottoms and sides of the Taff-fêchan and Taff-fawr valleys, between the Beacons and the northern boundary-line of the Carboniferous Limestone, are strewn with angular and rounded blocks of Old Red Sandstone: these erratics are found to have crossed the area of the Carboniferous Limestone in a southerly direction, and still further south, associated now with erratics derived from that formation, to have invaded the area of the Millstone Grit.

South of the northern outcrop of the Millstone Grit, erratics of that rock at once make their appearance, and from this point to the Eglwysilan mountain form by far the largest proportion of the Brecknockshire erratics.

The further advance of the erratics to the south was evidently considerably checked by the steep north scarp of the Coal-measures. Between Aberdare and Neath valleys the ground rises to the south over 1000 feet in some places, in a space of one mile, so that scarcely a single Brecknockshire erratic has found its way into the Rhondda valleys. South of this escarpment erratics of Brecknockshire Carboniferous Limestone entirely disappear. Erratics, however, of Millstone Grit and Old Red Sandstone are still met with in the Aberdare, Taff, and Taff-Bargoed valleys, the Millstone-Grit boulders being particularly plentiful in the Taff-Bargoed valley. A very large group of these erratics has been found by Mr. Edwin Corbett on the south side of the Eglwysilan mountain, 12 miles south of the northern outcrop of the Millstone Grit. Thousands of them lie inside the horseshoe formed by the mountain on its south side. They consist of angular and rounded blocks of Millstone Grit and Old Red Sandstone, some of the largest being from 6 to 7 feet in diameter, and weighing from 7 to 8 tons. The author noticed in two places a perfectly angular erratic of Millstone Grit touching a rounded block of the same rock, both being imbedded in what appeared to be Boulder-clay. At Cwm Sarn, a continuation of the Eglwysilan mountain to the S.W., there is a faintly grooved surface of Carboniferous sandstone about 200 yards to the south of these erratics. The trend of the grooves is  $9^{\circ}$  W. of N. and E. of S.; while the mean lie of the longest axes of seven large blocks here in position is  $36^{\circ}$  W. of N. and E. of S.



The Old Red Sandstone erratics have probably travelled from the Beacons, 20 miles distant, and bearing  $20^{\circ}$  W. of N. Some of the boulders are composed of the yellowish-grey variety of Old Red Sandstone. The Millstone-Grit boulders may have been derived from the precipitous western side of Twynau Gwynion, or Cefn-cil-sannus, in which case they have travelled in a direction corresponding with that of the grooves on the adjoining rock-surface. The highest point of the Millstone Grit at Twynau Gwynion, north of Dowlais,  $13\frac{1}{4}$  miles distant, is 1844 feet. This is the highest point attained by the Millstone Grit in the area embraced in this paper, if not the highest in the eastern part of the South-Welsh Coalfield. There is an outlier, however, of Millstone Grit capping Pen-cerrig-calch, two miles north of Crickhowell, in Brecknockshire, which is over 2000 feet above the sea-level. Pen-cerrig-calch bears  $18^{\circ}$  E. of N. from the Eglwysilan mountain, and is 20 miles distant. The height above the sea-level of the group of erratics at Eglwysilan is between 950 and 1050 feet. This gives a fall from Twynau Gwynion of 60 feet per mile, from Cefn-cil-sannus, 12 miles distant, of 23 feet per mile, and from Pen-cerrig-calch of about 60 feet per mile.

The lie of the longest axes of some of the principal erratics points in the direction of Cefn Cadlan and Gwern-cefn-y-garreg. The latter is 1444 feet high and 17 miles distant, giving a fall of 26 feet per mile. It bears  $40^{\circ}$  W. of N. from the Eglwysilan mountain. It seems improbable, from the smallness of the fall between the position of these erratics and their parent rocks, that they have been carried to their present resting-place on the surface of a glacier. From the texture of the Millstone-Grit boulders, the author thinks they are not derived from Pen-cerrig-calch. South of the Eglwysilan mountain, these Brecknockshire erratics are of rare occurrence. A small group of them is to be found in the "mixed" district at Caerau three miles west of Cardiff.

*The Glamorganshire Erratic district* extends north and south from the top of the Rhondda valley, at the northern outcrop of the Coal-measures, to Welsh St. Donats, near Cowbridge. On the east it touches the western boundary of the Brecknockshire erratic district from Aberdare to Walnut-tree Bridge, and may be divided from the "mixed" district by a line drawn from this last point to St. Nicholas. Westward it probably extends at least as far as the Neath valley. The Glamorganshire erratics in the area of the coal-basin are composed of Cockshot and Carboniferous sandstone, and are to be found chiefly in the Rhondda valleys and the Ely valley north of Llantrisant. The Cockshot boulders are generally angular and are to be found chiefly at heights of from 800 to 1000 feet above the sea-level. They are probably chiefly derived from the mountains on the south side of the Rhondda valley, between Pont-y-pridd and Pen-y-graig. West of Peterston, in the Ely valley, these erratics of Cockshot and Carboniferous sandstone are associated with boulders of Millstone Grit, Carboniferous Limestone, Old Red conglomerate, Lias, and Trias, which have all probably been derived from the areas of their respective formations south of the coal-basin.

They give a general indication of a southerly carry. Professor Ramsay mentions the occurrence of Chalk flints in this district. The author has seen them in Boulder-clay at Pendoylan,  $1\frac{1}{2}$  mile west of Peterston, but has not traced them further west.

*The mixed Erratic district* includes the Ely valley east of Peterston and the land lying between it and the river Taff south of the coal-basin. Besides Glamorganshire erratics, it contains, as already mentioned, a few boulders, probably derived from Brecknockshire, and Chalk flints.

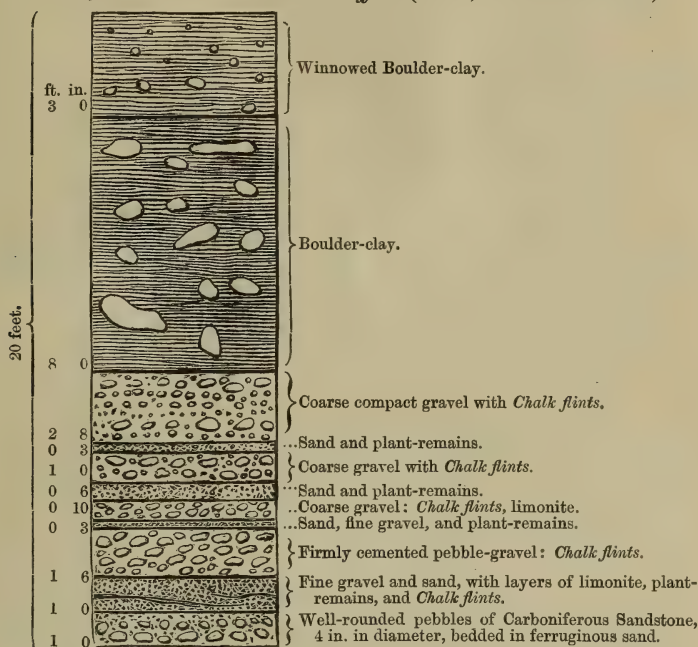
The positions of these erratics, as shown in the map, indicate a carry in a southerly direction; but whether from the south-east or south-west is uncertain. At Caerau there is a small group of Brecknockshire erratics; out of seventy of the largest boulders of this group examined by the author, 58 were Millstone Grit, 4 Old Red Sandstone, 4 Dolomitic conglomerate, 3 Cockshot, and 1 Carboniferous sandstone. Of the Millstone-Grit boulders, 26 were subangular, 21 angular, and 11 rounded. From the coarseness and toughness of the grit, the author thinks these erratics were derived from the northern and not from the southern outcrop of the Millstone Grit. This group of erratics lies between 80 and 190 feet above the sea-level, and, if they were derived from Cefn-cil-sannus, are 22 miles distant from their parent rocks. The fall is about 53 feet per mile.

The largest of these erratics is a subangular cubical block of coarse Millstone Grit, measuring  $4\frac{1}{2}$  feet  $\times$   $4\frac{1}{4}$  feet  $\times$   $2\frac{1}{4}$  feet at least.

The lie of the longest axes of ten large erratics, in position, does not show much persistency; three of these, however, lie with their lengths  $14^\circ$  E. of N. and W. of S., and one of them shows a shallow groove (?) on top running in the same direction.

*Chalk flints* have never been seen by the author north of the southern outcrop of the Coal-measures. They are tolerably abundant on the north and south sides of the Ely valley from Cardiff to Pendoylan. They have been found up to 400 feet above the sea-level on the hills between Cottrell and Coed-riglan, on the south side of the Ely valley. Nearly all these flints are subangular, and consist of waterworn (?) fragments, seldom more than two inches in diameter. They occur in the Boulder-clay of the Ely valley, as well as in its alluvial deposits. They are always more or less discoloured, with the exception of some which have been enclosed in a compact gravel underlying Boulder-clay at St. George's,  $5\frac{1}{2}$  miles west of Cardiff. The Chalk flints in this gravel retain their original colour remarkably well; they are associated in it with a few stones foreign to the neighbourhood, as quartz-porphry, veinstone, and Lydian stone. The position of the chalk flints in this gravel is shown in the following section (fig. 2). No Chalk fossils have ever been found by the author in Glamorganshire, nor have any traces of Chalk wash been seen in its Boulder-clay.

Fig. 2.—Section of Boulder-clay and Flint-bearing Gravel, Ely Valley, St. George's, near Cardiff. (Scale, 1 inch to 6 feet.)



Height above sea-level about 80 feet.

Gravel composed of pebbles of Carboniferous Sandstone, Carboniferous Limestone, Old Red Sandstone, Old Red Conglomerate, Millstone Grit, and Triassic Sandstone, the largest being 8 inches in diameter and only partially rounded. About 95 per cent. of the pebbles are Carboniferous Sandstone. Besides pebbles of quartz and Lydian stone, one of veinstone and another of quartz-porphry have been found associated with the Chalk flints.

2. *Boulder-clay* occurs in patches filling depressions over the whole area to which this paper refers. In most places it exhibits the same characteristics of a stiff, compact clay, varying in colour and composition according to the nature of the substratum. The included stones vary in size from mere pebbles to blocks 4 or 5 feet in diameter. Nearly all the stones in the Boulder-clay are smoothed, rounded, and often intensely glaciated, principally in the direction of their longer axes. Its thickness ranges from about 100 feet at Pont Sarn in the Taff-fêchan valley, to 30 feet at St. Fagans in the Ely valley. Its height above the sea-level varies from above 1200 feet at Dowlais Top to 20 feet in the Ely valley, at St. Fagans. The Ely valley Boulder-clay is distinguished from that of the coal-basin and south Brecknockshire by containing Chalk flints. These also underlie the Boulder-clay, as already stated, at St. George's in the Ely valley.

In the Old Red Sandstone area, south of the Beacons, the stones in the Boulder-clay consist entirely of angular, subangular, rounded, and intensely glaciated blocks derived from that formation. Going south into the area of the Carboniferous Limestone, stones are distributed through the Boulder-clay, at the places about to be mentioned, approximately in the following proportions :—

In the Neath valley  $\frac{1}{4}$  mile below Ystrad-fellte :

Old Red Sandstone.....	90
Carboniferous Limestone .....	8
Millstone Grit .....	2
	<hr/> 100

Included stones intensely striated, grooved, and polished ; Boulder-clay red, 12 feet thick, unstratified ; principal lines of glaciation on included stones frequently conform with direction of striæ on underlying rock-surface ; height above sea-level 740 feet.

In the Taff-féchan valley at Pont Sarn Railway-station :—

Old Red Sandstone.....	38
Carboniferous Limestone .....	62
	<hr/> 100

Boulder-clay in section 30 feet thick, unstratified, height above the sea-level 806 feet.

In the Taff-féchan valley between Pont Sarn and Pont Sticill :

Old Red Sandstone.....	20
Carboniferous Limestone .....	80
	<hr/> 100

Boulder-clay in section from 50 to 80 feet thick, composed of fractured masses of Carboniferous Limestone, crunched and bruised against one another and the Old Red Sandstone blocks, and more often roughly grooved and scratched than finely striated or polished, bedded in reddish-brown unstratified sandy clay. Height above the sea-level 808 feet.

Still further south, near Dowlais Top, where the Boulder-clay rests on Carboniferous sandstone, the percentage of different kinds of included stones is nearly as follows :—

Old Red Sandstone.....	3
Carboniferous Limestone .....	26
Millstone Grit .....	53
Carboniferous sandstone.....	18
	<hr/> 100

Boulder-clay in section about 15 feet thick, unstratified ; height above the sea-level about 1200 feet.

Three miles further south, at Abernant, near Aberdare, the Boulder-clay contains stones derived from different formations, nearly in the following proportions :—

Old Red Sandstone.....	3
Millstone Grit .....	12
Cockshot .....	2
Carboniferous sandstone .....	83
	<hr/> 100

Boulder-clay 9 feet thick, unstratified ; height above the sea-level 1130 feet.



At Navigation House, in the middle of the coal-basin,  $5\frac{1}{2}$  miles further south, there are only two per cent. of Old Red Sandstone and one per cent. of Millstone Grit in the Boulder-clay, the rest of the included stones being Carboniferous sandstone; it is unstratified here, and 350 feet above the sea-level. Nearly all the stones in the Boulder-clay of the Rhondda valleys and the Ely valley, as far as Llantrisant, are composed of Carboniferous sandstone or Cock-shot, the latter occurring angular more frequently than the former. This Boulder-clay is unstratified, so far as the author is aware, excepting near its surface, where it often shows signs of having been winnowed.

At Pendoylan and St. Fagans, in the Ely valley, the relative frequency of occurrence of different stones in the Boulder-clay is about as follows:—

*Pendoylan.*

Lias .....	18
Rhætic .....	9
Red Triassic sandstone .....	9
Light green dolomitic conglomerate.....	4
Carboniferous sandstone.....	51
Millstone Grit .....	5
Carboniferous Limestone .....	4
	<hr/> 100

Boulder-clay in section, 15 feet thick unstratified, brown and sandy; a stiff red Boulder-clay underlies it. A few Chalk flints in the upper Boulder-clay: height above the sea-level 160 feet.

*St. Fagans.*

Lias .....	38
Rhætic .....	1
Red Triassic sandstone .....	2
Red dolomitic conglomerate .....	8
Carboniferous sandstone .....	42
Millstone Grit .....	6
Old Red conglomerate .....	1
Old Red Sandstone.....	2
	<hr/> 100

Boulder-clay in section 15 ft. thick, unstratified, brown sandy clay; a few Chalk flints near surface; height above the sea-level 60 feet.

The stones in the Boulder-clay at Pendoylan and St. Fagans seem to have a tendency to lie with their lengths E.N.E. and W.S.W., while those in the Boulder-clay at St. George's, halfway between these two places, are arranged generally with their longer axes lying N.N.W. and S.S.E. Included stones in the Ely-valley Boulder-clay appear to be more delicately striated than those in the Boulder-clay of the coal-basin and Brecknockshire.

An analysis of the stones included in the Boulder-clay shows conclusively that the ice which formed it moved persistently in a southerly direction, as far, at any rate, as the southern outcrop of the Coal-measures. The strike of the different formations in Brecknockshire beyond the northern boundary-line of the Coal-measures runs nearly east and west; and no erratics from a southern formation have invaded the area of a northern.

Fig. 3.—Section of Quarry in Lower Lias, Ty-fry, St. Fagans, Cardiff, showing contortion and shattering of Strata by Ice, and intrusion of Boulder-clay. (Scale, 1 in. to 21 feet.)



A. An erratic of dolomitic conglomerate, the bottom and sides of which are ice-scratched in the direction of its longest axis.  
B, C. Rounded blocks of Lias scratched all over by ice.

D. A rounded knoll, probably a large *roche moutonnée*.  
Intruded Boulder-clay is indicated by a light horizontal tint.

As all the Boulder-clay in Brecknockshire examined by the author is unstratified, it may be provisionally assumed that it is the product of land-ice. From the occurrence of undisturbed sheets of Boulder-clay at the bottoms of valleys, as at Ystrad-fellte in the Neath valley, Pen-y-graig in the Rhondda-fawr valley, and St. Fagans and St. George's in the Ely valley, it may be inferred that the excavation of these valleys took place at some time previous to the final disappearance of the ice.

### 3. Shattered and contorted Rock-surfaces and intruded Boulder-clay.

—The rocks of South Brecknockshire and East Glamorganshire, which are soft and easily disjointed, are more often shattered and contorted than striated. This is the case in the Old Red Sandstone area south of the Beacons, and with many of the finely laminated sandstones of the Coal-measures and the Triassic and Liassic rocks of the Ely valley.

This shattering and contorting of rock-surfaces is much more common as an evidence of glaciation in the coal-basin than the grooving and striating of the surface-rock. It is to be met with everywhere, on the north, north-western, and north-eastern slopes of the Carboniferous-sandstone hills. In the Ely valley this rock-shattering is particularly well marked in the rocks belonging to the Lower Lias formation. At Ty-fry, near St. Fagans, there are several *roches moutonnées*, which illustrate the contorting and crushing power of ice and the intrusion of Boulder-clay. At Ty-fry, where a quarry has been opened in two of these *roches moutonnées*, the rock has been so much crushed as to form a *fine angular breccia*,

well adapted for gravelling drives and footpaths, for which purpose it is actually employed. Boulder-clay has been forced into the shattered strata to a depth of 12 feet at least. Ice-scratched stones are often to be found mingled with this débris, as shown in the accompanying section (fig. 3).

4. *Grooved and striated Rock-surfaces* are exhibited, under favourable circumstances, by three kinds of rock in this area—the Carboniferous Limestone, the Millstone Grit, and the Carboniferous sandstone, especially the Pennant rock. The Millstone Grit retains glacial markings on its surface even after long exposure to the weather; the Carboniferous sandstone shows grooves or striæ, if its surface has not been long exposed, or is sheltered by a thin covering of Boulder-clay; the Carboniferous Limestone quickly loses all trace of glaciation on exposure.

The furthest point east at which the author has seen striæ is at Craig-y-gaer, 5 miles west of Abergavenny, somewhat beyond the prescribed area of which this paper treats. The mamillated surface of the Millstone grit is here very faintly striated, the trend of the striæ being about  $70^{\circ}$  E. of N. and W. of S. The author was unable to determine from which end the striæ started; if from the east end, they may have been produced by the Scandinavian ice-sheet; if from the west, they may be due to a local glacier nearly conforming to the trend of the Clydach valley. Going westward, the next point at which the author has seen striæ is at Twyn-cilog, three miles north of Rhymney. Here their trend is about  $37^{\circ}$  E. of S., the ice which caused them having come from the north-west; the surface of the Millstone Grit here is mamillated; the height of the striæ above the sea-level is about the same as that of those at Twynau Gwynion,  $1\frac{1}{2}$  mile west, viz. 1840 feet; surface of Millstone Grit at Twynau Gwynion mamillated, trend of striæ  $36^{\circ}$  E. of S., pointing in the direction of the Brecknockshire Beacons.

This is the highest point above the sea-level at which striæ are known to the author. They are 7 miles distant from the Beacons, 2910 feet high, giving a fall of 153 feet per mile.

Proceeding westward, from Gwern-cefn-y-garreg, the striæ gradually swing round so as nearly to converge on the top of the Beacons. At the E. side of Cefn-cil-sannus their trend is  $12^{\circ}$  E. of S.; the surface of Millstone Grit is crushed, mamillated, grooved, striated, and polished; greatest height above the sea-level of striæ, as taken by aneroid, 1278 feet; fall from top of the Beacons 233 feet per mile. On the west side of Cefn-cil-sannus, the trend of the striæ is  $8^{\circ}$  E. of S.; at the east end of Mynydd Penmailard, first  $3^{\circ}$  E. of S., then, one mile further west, N. and S. The respective heights of these two last points above the sea-level are 1095 feet and 1199 feet, as taken by aneroid; fall from the Beacons of highest point 228 feet per mile. Between these two points there are several angular slabs of Old Red Sandstone, the largest measuring 4 ft.  $\times$  2 ft. 6 inches  $\times$  2 ft. 6 inches. There are a great number of angular and rounded blocks of Old Red Sandstone on the eastern slope of this mountain.

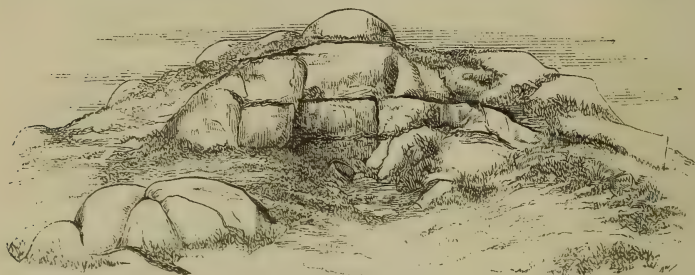
A mile and three quarters further west, on the same mountain, Q. J. G. S. No. 153.



the trend of the striæ is  $30^{\circ}$  W. of S.; at Cefn Cadlan they run  $38^{\circ}$  W. of S., and at Gwern-cefn-y-garreg  $42^{\circ}$  W. of S. All these striæ are on mamillated surfaces of Millstone Grit. At Gwern-cefn-y-garreg, their greatest height above the sea-level, as taken by aneroid, is 1444 feet.

The surface of the Millstone Grit here has been moulded into elongated domes and hummocks (fig. 4), showing a bare bright surface where they are not covered by peat or powdered rock. Wherever

Fig. 4.—*Roches moutonnées*, Gwern-cefn-y-garreg; Millstone Grit.



its surface has escaped being crushed, it has been well striated, grooved, and polished, the striæ pointing direct to the two tabular tops of the Beacons, distant 6 miles, giving a fall of 244 feet per mile. A mile S.W. of Gwern-cefn-y-garreg, on the right bank of the Mellte, 500 yards below Ystrad-fellte church, a recent slip of Boulder-clay has exposed a well-glaciated surface of Carboniferous Limestone. Where it has not been completely shattered, this rock has taken a fine polish, is firmly striated, and slightly grooved. This surface forms a steep slope in a bend of the river, which the ice must have struck obliquely at an angle of  $30^{\circ}$ . All its projections have been striated in a determinate direction, while the sheltered ledges show striæ running in various directions, often at right angles to the true lines of glaciation. The author thinks that all these striæ were formed contemporaneously. The strike of the Carboniferous-limestone beds here being nearly horizontal, and the bedding even and definite, the stones, which the ice was forcing obliquely up the slope would be arrested at the points of junction between the beds, and would have a tendency to slip along these lines of weakness, and scoop out steps in the slope, as has actually been the case. The direction of the grooves and coarse striæ is less persistent than that of the fine scratches, the former often describing a curve, which increases with the steepness of the slope. These striæ run down to the brink of the river Mellte, and were evidently continued below the present level of the valley-bottom. Their height above the sea-level here is 740 feet, giving a fall from the top of the Beacons, 7 miles distant, of 310 feet per mile.

The furthest point west to which the author has traced these striæ



on the Millstone Grit, is Pant-llwyd, half a mile S.W. of the last point. Their trend here is about  $38^{\circ}$  W. of S. Traces of them are probably to be found much further westward, as the striæ at this last point look very fresh and are firmly cut. The total extent of this striated surface of Millstone Grit from Twyn-cilog on the east to Pant-llwyd on the west is  $11\frac{1}{2}$  miles; and the striæ at either end make with one another an angle of  $75^{\circ}$ . This extent of convergence seems clearly to imply that the ice which produced these striæ radiated from the Beacons.

Going south, down the Neath valley, towards the steep scarp of the Coal-measures, a striated surface of Carboniferous sandstone is to be seen at the top of the cutting at the east end of the trend on the Neath-valley Railway, between Hirwain and Glyn Neath. This striated surface, which has been exposed from under a sheet of Boulder-clay from 12 to 15 feet thick, is fairly flat; and the trend of the striæ is about from  $80^{\circ}$  to  $85^{\circ}$  E. of N. and W. of S. The author was unable to determine the end from which the striæ started; if it be at the east end, as seems most probable, they may have been caused by glaciers from the Beacons deflected into the Neath valley by the steep northern scarp of the Coal-measures, or may be connected with the striæ at Craig-y-gaer, and be due to the Scandinavian ice-sheet; if they begin at the western end, they may be deflected striæ belonging to a great glaciation from the north-west, of which there are possible traces at many points in the area of the Coal-measures.

The author has not ascertained the height of these striæ above the sea-level; but they are probably not much over 700 feet, whereas Carn Mosyn, the highest point in the escarpment,  $2\frac{1}{2}$  miles south of this point, is 1971 feet high.

$1\frac{1}{2}$  mile east of Carn Mosyn a mamillated surface of Carboniferous sandstone is grooved and striated in a direction about  $58^{\circ}$  E. of S. Height above the sea-level, as taken by aneroid, 1530 feet, distance from Beacons 12 miles, fall 115 feet per mile.

$1\frac{3}{4}$  mile further east some faint scrapes (?) on a shattered surface of Cockshot point in about the same direction; their height above the sea-level is 1417 feet, as taken by aneroid; distance from Beacons  $11\frac{1}{2}$  miles; fall about 130 feet per mile.

Neither of these striated surfaces can be connected with the glaciers of the Beacons. At Abernant, near Aberdare, 4 miles eastwards, the trend of the striæ, on a mamillated surface of Carboniferous sandstone, is  $18^{\circ}$  E. of S. Their height above the sea-level is 1130 feet, as taken by aneroid; distance from the Beacons  $11\frac{1}{2}$  miles; fall about 170 feet per mile. At Navigation House, 7 miles distant from the last point, and bearing  $35^{\circ}$  E. of S., the trend of the striæ, on a mamillated surface of Carboniferous sandstone, is  $20^{\circ}$  E. of S.; height above the sea-level, as taken by aneroid, 350 feet; fall from the Beacons, 17 miles distant, about 150 feet per mile.

Bearing  $38^{\circ}$  E. of N. from last point,  $3\frac{3}{4}$  miles distant, there are striæ, on a smoothed surface of Carboniferous sandstone, on Gelligaer Common, about 300 yards N.N.W. from the ruins of Capel Gwladis.

Their trend is  $47^{\circ}$  E. of S.; height above the sea-level, as taken by aneroid, about 1320 feet; fall from the Beacons, 15 miles distant, 106 feet per mile. Bearing nearly due south from Gelligaer Common,  $5\frac{1}{2}$  miles distant, there is a faintly grooved flat surface of Carboniferous sandstone, near Cwm Sarn, on the south-east spur of the Eglwysilan mountain. Their trend is about  $9^{\circ}$  E. of S.; height above the sea-level 980 feet; fall from the Beacons,  $29\frac{1}{2}$  miles distant, about 94 feet per mile.

Bearing nearly due west from Cwm Sarn,  $3\frac{1}{2}$  miles distant, there are well-marked grooves on a mamillated surface of Carboniferous sandstone, near the "Rocking-stone," Pont-y-pridd. The impact-surface ("Stosseite") of this hill, as of most of the hills in the coal-basin, is too much shattered to show striæ. The trend of the grooves here is about  $7^{\circ}$  E. of S., or nearly parallel to the grooves at Cwm Sarn; height above the sea-level, as taken by aneroid, 360 feet; fall from the Beacons,  $19\frac{1}{2}$  miles distant, about 131 feet per mile. Passing now to the Rhondda valley, west of the Taff valley, faint striæ are discernible on a faintly ground surface of Carboniferous sandstone, near Pen-y-graig, in the Rhondda-fawr valley. Their direction is from  $30^{\circ}$  to  $40^{\circ}$  E. of S., following the trend of the valley. Their height above the present level of the valley-bottom is about 40 feet. They bear  $68^{\circ}$  W. of N. from the striæ near the "Rocking-stone,"  $5\frac{1}{2}$  miles distant; distance from the Beacons 18 miles.

Bearing nearly due east of the Pen-y-graig striæ,  $4\frac{1}{2}$  miles distant, between Cefn and Lan farmhouses, a mamillated surface of Carboniferous sandstone has been exposed from under some rubble in making a road. This is grooved and striated in a direction about  $33^{\circ}$  E. of S. Its height above the sea-level, as taken by aneroid, is 555 feet; distance from the Beacons  $18\frac{1}{2}$  miles; fall about 127 feet per mile.

Bearing  $17^{\circ}$  W. of S. from the "Rocking-stone" striæ,  $\frac{3}{4}$  mile distant, are some faint striæ on a rounded surface of Carboniferous sandstone, running  $26^{\circ}$  E. of S.; height above the sea-level, as taken by aneroid, 482 feet; distance from Beacons a little over 20 miles; fall about 128 feet per mile. Bearing  $8^{\circ}$  W. of S. from this last point, one mile distant, an extensive striated surface of Carboniferous sandstone has recently been exposed from under a covering of Boulder-clay from 5 to 6 feet thick, at Maendu quarry, near Treforest. Trend of striæ nearly due N. and S.; surface flat, height above the sea-level 705 feet.

This is the southernmost point in the whole area at which the author has seen a striated rock-surface. The distance from the Beacon is 21 miles; fall 105 feet per mile.

*Summary.*—It would be premature for the author, in the present imperfect state of his knowledge, to attempt to systematize all these glacial phenomena; as, however, a few points seem already established, it may be well to state them.

I. The erratics in the Eglwysilan and Caerau group were probably transported by floating ice. This is implied (1) by the

smallness of the fall between the levels of the resting-places of these erratics and that of their parent rocks, (2) at Cwm Sarn by the want of conformity between the lie of the longest axes of the erratics and the trend of the grooves on the neighbouring rock-surface. This point, however, needs to be more fully worked out before it be accepted as true. (3) The contact in this group of perfectly angular and rounded boulders can be most easily explained on the hypothesis of an ice-foot, transporting a mixed load of water-worn or glaciated boulders from shore-lines and angular rock-fragments from overhanging cliffs. No definite conclusion can as yet be arrived at with reference to the rest of the boulders, with the exception perhaps of those composed of Old Red Sandstone, in South Brecknockshire, the frequency with which these erratics occur angular, and the certainty of land-ice having once radiated from the Beacons, justifying the inference that many of them are the relics of old moraines.

II. The Boulder-clay of South Brecknockshire is chiefly the product of land-ice; for (1) it is unstratified; (2) its included stones are intensely glaciated; (3) angular stones greatly predominate over rounded; (4) in one case the largest of the included stones were observed to lie with their lengths parallel to the lines of glaciation on the underlying rock-surface.

III. The striated rock-surfaces of South Brecknockshire have been formed by land-ice, descending existing valleys, from the Beacons, at least as far south as the edge of the Coal-measures. South of this line the striated rock-surfaces present a more complicated problem. Those at the Craig-y-gaer and at the top of the Rhondda-fawr valley can hardly be attributed to the glaciers of the Beacons; and yet the former were certainly, and the latter probably, caused by land-ice.

In the coal-basin the striæ having a S.E. trend and occurring at high levels may be due to the glaciation of an ice-sheet coming from the N.W., or the grounding of icebergs; the mamillated surfaces, however, point to land-ice as the agent. The striæ which are found at lower levels in the Taff and Rhondda valleys may be due to (1) this N.W. ice-sheet, (2) the glaciers of the Beacons, (3) glaciers having their origin in the coal-basin.

The difference of direction in which the low-level striæ run as compared with the high-level, *e. g.* near Pont-y-pridd, may be due to the land-ice conforming more and more to the trend of the valleys as it became localized, or to their belonging to a glaciation altogether more recent.

The author has received much valuable advice from Professor Prestwich. He has also to acknowledge the important help given him by Dr. C. T. Vachell, M.D., Mr. W. Adams, F.G.S., and many other members of the Cardiff Naturalists' Society.

## DISCUSSION.

The CHAIRMAN (Dr. J. Gwyn Jeffreys) said that the district was well known to him, and that he had examined parts of Glamorganshire with reference to the present question, and he believed that there was evidence there of land-glaciation only, the remains of moraines being occasionally discernible—differing in this respect from the northern counties of Wales and England, which give unmistakable indications of marine action, and sometimes at a present height of over 1300 feet. In the southern counties of England there was a similar absence of so-called glacial shells, and no evidence of elevation. He invited discussion on this interesting communication.

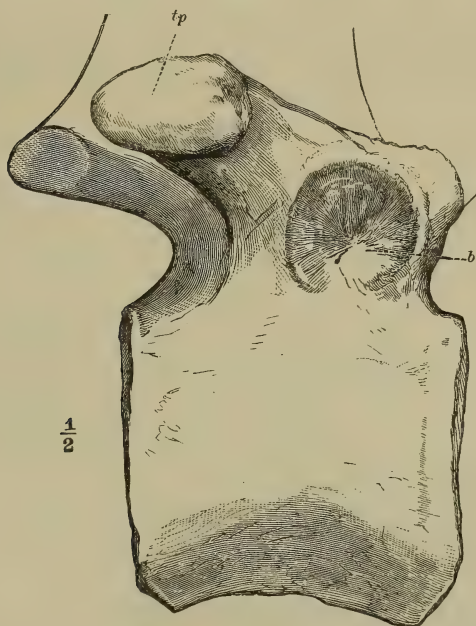
Prof. PRESTWICH expressed his regret at the absence of the author, and his sense of the value of the paper. It formed an excellent supplement to Mr. Mellard Reade's important paper, to which the Society had already listened. The south of Wales had hitherto received but little notice as compared with North Wales. One distinction to be noticed in this district was that the erratics were local, while in North Wales erratics were present from districts far to the north. It was singular that south of the Bristol Channel the indications of ice-action should be so obscure and uncertain, when they were so clear to the north of it.



5. *On the DORSAL REGION of the VERTEBRAL COLUMN of a new DINOSAUR (indicating a new Genus, SPHENOSPONDYLUS), from the WEALDEN of BROOK in the ISLE OF WIGHT, preserved in the WOODWARDIAN MUSEUM of the UNIVERSITY of CAMBRIDGE. By Prof. H. G. SEELEY, F.R.S., F.G.S., &c., Professor of Geography in King's College, London. (Read June 21, 1882.)*

THIS small series of six vertebral bones is remarkable for the great lateral compression of the centrum and the depressed form of the neural arch, and, as exhibiting the characters of the dorsal region in a new generic type, seems to me worthy of some notice.

Fig. 1.—*Dorsal Vertebra of Sphenospondylus, right side of type specimen in Woodwardian Museum. (One half nat. size.)*



b. Facet for head of rib.

tp. Transverse process.

The centurms of the vertebræ have an average length of 9 centim. each; the transverse width of the articular faces is about 7 centim., with a vertical depth of at least 8 centim.; but the lower part of the centrum is much compressed from side to side, so as to have a wedge form, and terminates inferiorly in a sharp longitudinal ridge. The articular margins of the centurms are moderately elevated. The transverse processes of the neural arch are at first directed back-

ward, but soon become directed transversely outward, and retain their upward direction. The facet for the head of the rib is at first large, and at the base of the transverse process, and bounded posteriorly by the sharp ridge which runs below the transverse process to the hinder margin of the neural arch; but after a time the rib-head rises higher, so as to be chiefly above the zygapophysial facet; and then it becomes smaller, the ridge behind it more or less disappears or rounds away, and the transverse process, which was at first triangular in section, becomes vertically compressed and thin.

The interest of the series is in exhibiting the gradation of characters as the bones extend backward, though, as the surfaces are invested with a thin argillaceous layer, and the bones have lost the neural spines, there is still something to be desired in their condition.

In the 1st vertebra the anterior face of the centrum is flattened, but somewhat concave, except towards the margin, which is convex. The basal outline of the face is rounded, the sides are subparallel, and the superior corners are rounded, while the neural canal is concave. The median vertical measurement is 7.4 centim., the transverse measurement nearly 7 centim. The measurements of the posterior surface are slightly less; but the articular face is more concave, and its convex outer border is narrower.

The sides of the centrum are concave from front to back, and moderately convex from above downward, becoming closely approximate towards the base, so as to form a blunt basal ridge or keel, which is most developed towards the anterior end: it is concave in length. The transverse measurement in the middle of the centrum below the neural arch, is 5.3 centim.

The neural arch encloses a rather small neural canal, which is not higher than wide. The zygapophysial facets are inclined at a right angle, are  $2\frac{1}{4}$  centim. broad, and parted below by an interspace about 1 centim. wide. The external surfaces of the anterior zygapophyses are oblique, extending, with a slight concavity, back to the elevated border of the facet for the head of the rib, and extending concavely downward to form the pedicle, which joins the centrum by an imperceptible suture.

The facet for the head of the rib is large, vertically oval, less than 4 centim. deep, and  $3\frac{1}{2}$  centim. wide; it is deeply concave, in advance of the middle of the side, 8 millim. below the anterior border of the transverse process, which extends behind it, and above its posterior half. These facets are not quite vertical, the transverse measurement over their upper parts being more than the measurement at the base. Below the base of this rib-facet there is a slight convexity on the line of the neurocentral suture.

The transverse processes are strong and directed upward and outward, almost at the same angle as the zygapophysial facets, but they are also directed a little backward. The superior surface is flattened, smooth, looks inward and upward, 7 centim. wide at the base, with the margins compressed and gently concave in length, though the concavity is deeper on the posterior side, where it

terminates above the posterior zygapophyses. At the terminal facet for the tubercle of the rib the width of the process is about 3 centim. Inferiorly the transverse process is compressed into a strong ridge, the base of which is rounded; this ridge descends posteriorly behind the facet, for the head of the rib to form the anterior margin of the canal for the intervertebral nerve, while at the free end of the process it expands to assist in forming the transversely ovate tubercular articular facet. The anterior and posterior inferior surfaces of the process are concave channels, which deepen as they descend, the posterior enlarging into a considerable excavation between the vertical buttress and the posterior zygapophysis. The transverse width over the transverse processes, as preserved, is about 17 or 18 centim.

The base of the neural spine is about 9 centim. long. It is broken away, but was compressed, widening posteriorly, where it is about 1 centim. thick at the fracture. It there descends, widening in an A shape, with the lateral part concave; and the flattened posterior surface extends backward, to terminate inferiorly in the ovate posterior zygapophysial facets, which are divided behind by a slight concavity, which becomes narrower as it extends between them inferiorly. The transverse width over the two facets is 5 centim.

As is usual in dorsal vertebræ, the superior border of the centrum is a little longer than the inferior border, indicating a slight arching of the back.

The 2nd vertebra differs chiefly in having the anterior articular face flatter, and in having a more elevated ridge margining the anterior border of the articulation for the head of the rib, while the ridge below the transverse process is directed less backwards, and more obviously curved.

In the 4th the inferior ridge of the transverse process is nearly transverse, and more obviously forms the posterior border for the articular facet for the rib.

In the 5th this ridge is inclined backward, and the posterior border of the neural spine is rounded.

The 6th and last vertebra of the series is a little crushed, so that the inferior basal ridge appears to be either obliterated or less developed. The base of the neural arch below the transverse process has now become a somewhat compressed area, rounding anteriorly into the pedicle of the neural arch, slightly concave in the middle, and margined posteriorly by the broad flattened rounded ridge descending from the transverse process. Behind this ridge is a deep impression like a thumb-mark on plastic substance. The tubercle for the rib has now ascended so as to be quite on a level with, or rather above the transverse process, and immediately in front of it; and it has become smaller. It is wider than deep; and the measurements are between two and three centim. Its superior surface is convex; and the convexity extends inward towards the neural spine. The greater part of it rises above the level of the zygapophysial facet,

external to which it projects laterally more than a centimetre. The facet is still concave, with a central pit.

Fig. 2.—Sphenospondylus, *left side of a Dorsal Vertebra*. (Fox Collection, Brit. Mus.  $\frac{R}{142}$ .) One half nat. size.



b. Facet for head of rib.  
z. Postzygapophysis.

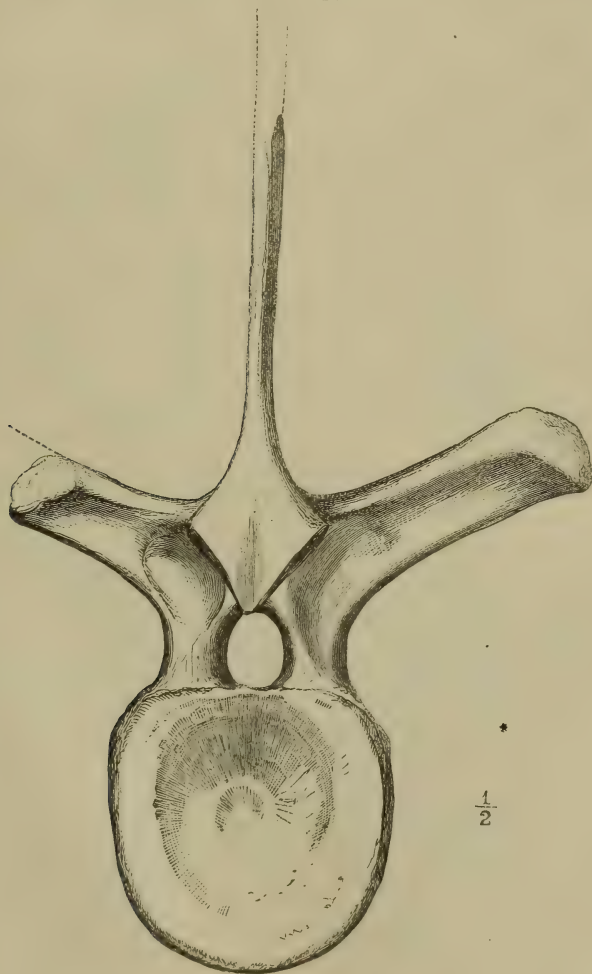
tp. Transverse process.



The anterior zygapophyses do not reach so far forward as to be quite level with the anterior face of the centrum.

I have long been seeking for specimens with which this series might be compared; and although the old collection of the British Museum contains but one centrum of this type, Mr. Davies, of the British Museum, on seeing these vertebræ, at once drew my attention to a series of more than a dozen in the Fox Collection,  $\frac{R}{142}$ , which belong to the same species (fig. 2). I am inclined to think that many of them may have been part of the same individual with the

Fig. 3.—*Posterior Aspect of Dorsal Vertebræ of Sphenospondylus.*  
(Fox Collection, Brit. Mus.  $\frac{R}{142}$ .) One half nat. size.



$\frac{1}{2}$

Cambridge bones. The length of the centrum is the same, and its wedge-like character identical. The surface behind the transverse processes, which is not clearly seen in the Cambridge bones, is found to form a wedge with lateral excavations, which extend forward under the posterior expansions of the transverse processes.

In several vertebræ there are slight pits at the base of the anterior margin of the neural spine, and well above the large deep depression bordered by the zygapophysial facets, between which the sharp anterior margin of the neural spine is prolonged. The notch between the zygapophyses only extends for their anterior third.

A few vertebræ have the neural spine preserved, but it is not perfect. In one (fig. 2) it is  $16\frac{1}{2}$  centim. high, 9 centim. wide at the base; it contracts a little in the middle, chiefly by concavity of the posterior border, widening a little above, so as to make both margins concave.

All the British-Museum specimens show the facet for the head of the rib, though it varies much in character. At first it is small (b, fig. 2, p. 58) vertical, and low in position. Gradually ascending, it widens and becomes more circular. And when the transverse processes become horizontal, the superior and anterior margins become greatly elevated. In the hinder part of the series the facet becomes small and transversely oval.

I have seen neither cervical nor caudal vertebræ which present this type. The Cambridge specimens were obtained by Mr. Keeping in 1866, and brought to the Museum with the coracoid lately described; but he has no recollection of their having been associated with that bone. But in view of the likelihood of these vertebræ pertaining to the "*Iguanodon Seelyi*," I have refrained for the present from giving a specific name to the specimens.

The characters on which I establish the genus *Sphenospondylus* for these remains are the laterally compressed form of the base of the dorsal centrum, the depressed form and character of the neural arch, the upward inclination of the transverse processes, and the condition of the facet for the head of the rib in rising so as to be placed between the transverse process and the anterior zygapophysis. These characters clearly differentiate it from *Iguanodon*, which is the only genus with which it can be compared, supposing that we take *Iguanodon Mantelli* as the type (figs. 4 & 5). But the genus has since been enlarged to include such types as *Iguanodon Prestwichi* and *I. Seelyi*, both of which differ from the type in well-marked and varied characters. What the significance of those differences is may, I fancy, be determined by comparing together existing genera of animals, and noticing the nature of the characters by which they differ. Judged in this way, I think it possible that both these species might be referred to new genera; and from such a point of view I conceive of these vertebræ as indicating a new genus. But if we take the older conception of a genus, which is anatomical and not zoological, and more a matter of palæontological convenience than a step in evolutionary history, we may rank all these forms under the one name *Iguanodon*. It is a matter on which there is

Figs. 4 & 5.—*Posterior and left lateral view of Dorsal Vertebra of Iguanodon Mantelli.* (From the specimen figured by Prof. Owen, in the 'Wealden Reptiles,' suppl. ii. pl. vii. figs. 4 & 5.) One eighth nat. size.

Fig. 4.

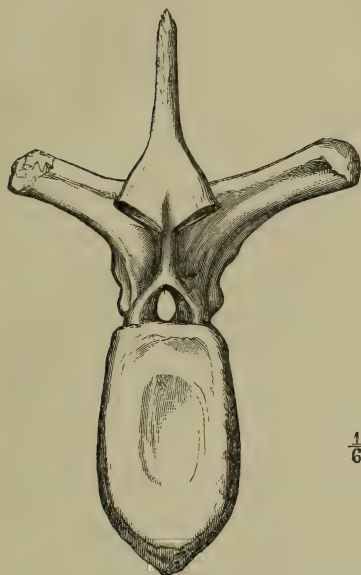


Fig. 5.

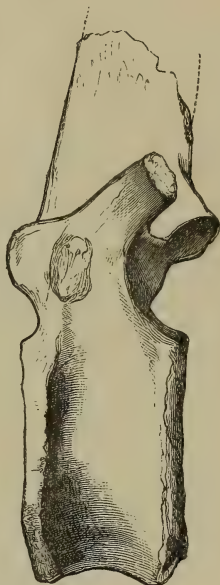

 $\frac{1}{6}$ 

Fig. 4. Posterior view, for comparison with fig. 3.

Fig. 5. Lateral view, for comparison with figs. 1 &amp; 2.

likely to be difference of opinion for some time to come. And if I lean towards defining genera so as to make them small, it is because I believe that characters are in this way better appreciated, and because the groups of fossils become better comparable with existing natural-history types. I have compared the vertebræ here described with those of *Iguanodon Prestwichi* and other available named *Iguanodons*, and believe that the character of the neural arch justifies my distinction, though the types have some characters in common.

#### DISCUSSION.

The PRESIDENT said that he had been long familiar with vertebræ of this type, and had had a strong suspicion that they would prove to belong to *Iguanodon*.

6. *On the MECHANICS of GLACIERS, with especial Reference to their supposed POWER of EXCAVATION.* By REV. A. IRVING, B.A., B.Sc., F.G.S. (Read December 6, 1882.)

OPINIONS as to the kind and extent of work done by glaciers upon the rocks over which they move seem still to be very divided in the geological world. On the one hand it is still maintained that these agents are capable of excavating basin-like hollows, such as those which are now (or have been) filled with lakes; on the other hand we find such high authorities as Profs. Bonney\* and Credner† rejecting the hypothesis of *excavation*, while they fully recognize (as every Alpine observer must do) the scouring, grooving, striating and polishing work done by glaciers upon the floors and sides of valleys previously formed by ordinary valley-erosion, as well as their indirect action in contributing to the formation of lakes by the dams which their moraines form (*e.g.* at the southern end of Lake Garda) in some cases across valleys. Amid this diversity of opinion I may be pardoned for attempting to add something to the discussion of this interesting subject.

The whole discussion would seem to narrow itself, theoretically, to the answer to be given to the question, *Can a glacier dig or excavate basin-like hollows?*

Those who answer in the affirmative seem in their arguments to assume that the ice of the glacier moves as a *rigid mass*. If it did so, its scooping-out power would be enormous; but that it does not has been shown by Prof. Tyndall, in his little work 'Forms of Water' and elsewhere, and demonstrated experimentally by himself and Prof. Helmholtz‡ of Berlin. The writings also of Forbes and others on this subject are no doubt familiar to geologists.

The snow of the upper *névé* becomes gradually transformed into the solid ice of the glacier in two ways:—(1) By pressure from above the crystalline particles are partly melted, the liquefied portions finding their way between those which still remain solid; (2) the heat of the sun melts the surface-particles, the water at 0° C. thus formed trickling into the snow. In both cases the water is again transformed into ice, its latent heat being taken up by the snow, which at these high altitudes is at temperatures below 0° C. *Regelation* occurs, as it does behind the shearing-wire in a well-known experiment. Liquefaction by *pressure* of portions of the ice-mass, and regelation at points where the pressure is relieved, are not confined to the *névé*; it goes on continuously throughout the mass of the glacier, though more in some parts than in others, and goes a long way to account for the "plasticity" of the ice-mass—its power, that is to say, of adapting itself to the form of the trough or hollow in which it lies.

\* See Quart. Journ. Geol. Soc. vol. xxx. p. 479.

† 'Elemente der Geologie,' p. 245. ‡ *Vide* Lecture, 'Eis und Gletscher.'



Prof. J. Thomson has deduced from the mechanical theory of heat, and Sir W. Thomson has verified by experiment, the law that *the freezing-point of water is lowered by pressure*; and Helmholtz \* has shown how it follows, as a corollary to this important law, that the temperature of ice is lowered when it is subjected to pressure within a confined space, the ratio of the liquid water to ice being at the same time increased. The thermal energy which is generated by pressure becomes latent in the newly liquefied ice, and so is not available to affect the temperature of the mass. This liquefaction must take place most in the lower layers of the glacier; and owing to the great latent heat of water (=nearly 80 thermal units at a pressure of one atmosphere) the pressure, though great, melts only a small proportion of the ice-mass, which is very large. Helmholtz † has pointed out the bearing of this principle upon glacier-work. The ice being pressed, and a small portion of it melted, the water is free to escape. The temperature of the pressed ice is lowered, but not that of the water, which, being free to escape, does not suffer any lowering of temperature. "So we have, under these circumstances, ice colder than  $0^{\circ}\text{C}$ . in contact with water at  $0^{\circ}\text{C}$ . The consequence of this will be, that water is continually frozen around the pressed ice and forms new ice, while a portion of the pressed ice is melted." Owing partly to imperfect homogeneity of the ice of a glacier, partly to the inequalities of its bed, pressure acts more upon some points and in some directions than in others. Several results may follow. (1) If the pressure is applied continuously and rapidly enough, and the temperature of the ice is below that required for liquefaction under the given pressure, the ice cracks; work is done in overcoming cohesion. (2) Some ice is melted, mechanical force is transformed into heat, which becomes latent in the melted ice, the water is squeezed out and regelates in contact with the colder ice, its latent heat being given up to the colder ice in contact with it, raising the temperature of this ice, until it and the regelated film have acquired again a uniform temperature. (3) *Friction* follows, if, as in the glacier, the force continues to be applied, by the faces of the cracks sliding over one another. Heat is generated; portions of the ice surfaces are liquefied, the water trickling out as before and becoming regelated in contact with colder ice, the thermal energy given up by it in the act of regelation being diffused by slow conduction, as before. (4) As the heat given up by the water in the act of regelation to the contiguous ice is transmitted by slow conduction through the neighbouring ice, it causes expansion, or a tendency to expand, which can only be prevented by increase of resistance. (5) If expansion occurs, as in (4), or water trickles out, as in (2) and (3), its tendency will be, under the influence of gravitation, rather downwards than in any other direction; and so the centre of gravity of the whole mass is lowered, though the mass may not be moving as a rigid body. This I conceive to be the outline of the history of the expenditure of that portion of the potential energy of the weight of

\* 'Eis und Gletscher.'

† *Loc. cit.*

a glacier-mass which is used up *within* the glacier. Now for the bearing of this upon the question of excavation.

Exactly so far as the glacier-mass possesses this yielding property due to the transformation within it of the mechanical energy due to its weight, *is its digging- or excavating-power diminished*. Further, whatever theory we adopt to account for the yielding property of ice (its "plasticity" or "Nachgiebigkeit"), it is plain that the forward and downward thrust is not wholly expended in propelling the glacier mass as a rigid whole; hence the absence of any traces of excavating-action where glaciers have receded in recent years. As it is, the forward thrust is to a very large extent resolved into an indefinite number of smaller forces, which are expended, either directly or indirectly (if first transformed into thermal energy), in overcoming cohesion. It follows at once from this, as a simple deduction from the law of the conservation of energy, *that the residuum of energy available for any supposed excavating action of a glacier is comparatively small*. And this deduction would seem equally sound whether (following Tyndall and Helmholtz, as I have done above) we adopt the *regelation-theory*, or the "viscous theory" which was propounded by Forbes, to explain the "flow" of the glacier. The essential point is, that the greater part of the forward thrust of the glacier mass is expended in overcoming cohesion and in causing movements among the parts of a glacier relatively to one another. Such relative movements of the parts of a glacier are, since the numerous observations of Tyndall and his fellow glacialists, too well known to need further description here; the relative rates (1) of the middle and the sides, (2) of the top and bottom, having been made matters of exact measurement\*. Tyndall and Helmholtz have both also given experimental demonstrations of them.

The above reasoning applies of course to such portions of the glacier as form a continuous whole. There is yet another way in which some part of the potential energy due to weight is expended; that is, in the *formation of crevasses*. Ice is not viscous, and therefore does not preserve its continuity under the influence of *tensile strain*. So small is its power to resist tensile force, that the slight bending of its mass which is caused (according to Helmholtz) by an increase of gradient in its bed of from  $2^{\circ}$  to  $4^{\circ}$  is enough to form *transverse crevasses* in its upper surface. Such crevasses penetrate further into the ice in proportion as the increase of gradient is greater. Here then is an expenditure of a portion of the weight of the ice-mass immediately below each crevasse, which is quite unavailable for purposes of erosion. Again, in the formation of the well-known *Bergschrund*, the ice below it having torn itself away from the *névé* above it, the weight of the latter is no longer capable of cooperating with the weight of the ice below it. *Marginal crevasses* result also from the same absence of ductility in ice. The movement forwards and downwards of the central parts of a glacier being greater than that of the lateral parts, which are retarded by friction against the sides of the valley, a strain and tear result;

\* *Vide* 'Forms of Water,' by Prof. J. Tyndall.

the ice parts asunder in a number of planes, forming an equal number of crevasses, which proceed with gradually diminishing width from the extreme lateral limits of the glacier towards the centre—not, however, in a strictly transverse direction, but in that of the tangent to the direction of the strain, tending upwards therefore towards the source of the glacier. Finally *longitudinal crevasses* are formed when a glacier has to force itself through a narrow gorge. As it emerges from the gorge, the central portions move on faster than the lateral portions, which are retarded by the sides; and that portion of energy (even here where the action against the rocky sides is at a maximum) which is expended in parting the middle portions from, and producing friction of them within the gorge against, the lateral portions, cannot be expended at the same time upon the work of erosion. Generally, we may say that the origin of all these varieties of crevasse is the same property of glacier-ice which makes it unable to yield to tensile force; and the consequence is, in each case, a breaking-up, more or less, of the glacier-mass, and the consequent distribution of its force as a moving body.

The whole weight of any given mass of the glacier may be resolved into two forces, the one acting parallel, the other at right angles, to the inclined plane on which the glacier lies\*. The former, which will vary with the sine of the angle of inclination, and will therefore be *nil* when the glacier rests on a horizontal bed, is, as has been shown, partly used up within the glacier; and the portion thus used up, whatever it may be, is not exerted against the rocky floor, and therefore *can do no work in the way of erosion*. The ice moves on this floor, if it be inclined at a sufficient angle; but it moves with less velocity at its bottom than the centre of gravity moves.

\* The relation which subsists between the angle of inclination of the slope on which a given mass of a glacier lies, and the pressure and shoving force due to the weight of the given mass, will be made clearer by the following simple mathematical reasoning. Suppose a given glacial mass to lie on a slope, represented in the accompanying

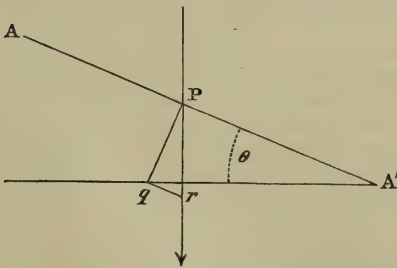


diagram by a line  $AA'$ , which makes an angle  $\theta$  with the horizontal; and let us suppose the whole weight of the given mass to be represented by one resultant force  $W$ , acting vertically through its centre of gravity, upon the point  $P$ , as indicated by the arrow. By a simple "triangle of forces" it is easy to see what parts of the weight  $W$  are represented by the forces acting (1) as pressure in the direction of the normal  $Pq$

upon the surface  $AA'$  at  $P$ , (2) as a shoving force parallel to  $AA'$ . For the first we have

$$W \times \frac{Pq}{Pr} = W \times \cos \theta;$$

for the second,

$$W \times \frac{Pr}{Pr} = W \times \sin \theta.$$



So far as we have now proceeded in the argument, this difference of velocities would appear to represent the work done within the glacier; and we might reason in a similar way as to the difference of velocities of the median and marginal portions.

In the above reasoning I have assumed only the action of a part of the shoving force due to gravity in making the glacier slide upon its bed. As a matter of fact, other causes may promote sliding by diminishing friction, such as (1) the non-contact of the ice with the rocks in places where the glacier streams are flowing, (2) the thermal effect of the heat flowing from the earth's crust by conduction from below, (3) comparatively warm water rising in places from deep-seated springs, (4) the partial liquefaction of the ice by pressure against the rocks. All these, by diminishing friction, dispense with some portion of the shoving force due to gravity; so that the proportion of that force used up within the mass of the glacier is even much greater than the estimate from the difference of velocities alone would give.

So far as any supposed excavating action is concerned which could form rock-basins, the *differential* movement of the upper portion of the glacier, as compared with its base, is the most important point. Measurements taken by Prof. Tyndall in the case of the Glacier du Géant, at the foot of the Tacul, showed a movement of the portions near the surface more than double that of the base. *A fortiori*, this differential movement must be greater, owing to the greater retardation of the base of the glacier, when on a horizontal bed—so much so, that the greater pressure acting at right angles to that bed (which varies *cæteris paribus* with the cosine of the angle of inclination of the bed) would seem to avail nothing, since the movement of the base of a glacier lying upon a horizontal bed would be *nil*. The only propelling force to which it could be subjected would be the shoving force acting against it from the weight of the glacier lying upon an inclined slope immediately above. Prof. Tyndall\* has shown us how this would act. When the glacier passes from a steeper to a less steep gradient, the crevasses close up, the yielding-property of the ice comes into play, the ice at the surface is thrown into a series of transverse terraces or huge wrinkles, the differential motion is increased so much that stones of the medial moraine, which have fallen into the crevasses, are brought again to the surface. From all which it would appear that the movement of the *base* of the glacier upon a horizontal bed is *nil*; and therefore here, where a theory of excavation most requires it, its erosive action is almost *nil*. This reasoning seems further confirmed by observations made on the Morteratsch†. Some distance up the glacier the movement, at its maximum, was found to be 14 inches *per diem*; yet at the snout, which lies on a nearly horizontal bed, even without any ice in front to offer any resistance to its motion, the movement forward was only 2 inches in a day. It is no reply to this argument to say that, higher up, the erosive power must be greater. The ordinary law of valley-contour,

\* Forms of Water, p. 180.

† *Ibid.* pp. 96, 97.



the steepness of the valley as a rule increasing as we approach its head, is well known; and it follows from this that the biting-power of the glacier upon the rocks (which diminishes with the steepness in proportion to the cosine of the angle of inclination) is less as we ascend into the steeper slopes of the glacier-region. Moreover it is self-evident that it is not on such steeper parts of the valley that the advocates of the excavation-theory would call its action into requisition.

In the work of erosion, such as is imputed to glaciers, it is of course well known that the work is mainly done by the stones and sand which have found their way, either through crevasses or between the glacier and the rocky sides of its channel, to the base. These form the teeth of the file. We must recollect however (1) that these and the rocks upon which they act are of about equal hardness; only at most, therefore, one half of the finer detritus which comes away in the glacier-stream is produced by the grinding away by these stones of the rocks themselves, the wearing of the stones furnishing an equal amount of it; (2) that the stones held in the ice are only passive instruments, and can only do work upon the rocks when they move—that is, when the resistance to their motion against the rock is less than the yielding-power of the ice which holds them. Moreover, much of the detritus which comes away in the glacier-stream may well be derived directly from the finer portions of the moraines which have fallen to the bed of the glacier.

It has been suggested that the freezing of water within the crevices and pores of the rocky bed of the glacier must by its expansion break up the rock-surface, and thus furnish detritus for the glacier to carry away, as the loosened materials are caught up by the ice. This *primâ facie* seems a sound argument in favour of excavation; we must therefore examine it. We must recollect (1) that the water contained in this way within the rock is exposed to subterranean heat passing up by conduction from below, and that, if this is slow, owing to the low conductivity of the rock-materials, the cooling effect of the ice of the glacier is, *à fortiori*, equally slow. (2) The actual surface of the rock at any given point is in contact with either (*a*) the water of the glacier-stream, which is not below  $0^{\circ}\text{C.}$ , and therefore cannot freeze the water within the rock, or (*b*) in contact with the ice (or a stone stuck in the ice and at the same temperature as the ice), in which case the ice may be either at or below  $0^{\circ}\text{C.}$ , according to the pressure at the point of contact, as Helmholtz's reasoning shows. Ice at  $0^{\circ}\text{C.}$  has no power to freeze water at  $0^{\circ}\text{C.}$ , since with equality of temperature there can be no exchange of heat between the bodies; and if the ice be below  $0^{\circ}\text{C.}$  it can only be so at a pressure proportionately greater. This very pressure must be exerted upon the rock, and so counteract the expansive force of the water within the rock. The hypothesis is thus shown to be wholly inadmissible. Further, the actual appearance of glaciated rocks shows that they have not been thus broken up by freezing water while the glacier covered them.

It is conceivable that some of the surface-portions of the glacier

which are melted by the sun's heat or by a warm current of air may, in penetrating the glacier, come into contact with ice which is locally colder than  $0^{\circ}\text{C}.$ , and in this way undergo refrigeration. If this took place anywhere around a surface of contact of the ice and the rocky bed, the surface of contact being increased (as Helmholtz has shown in the valuable notes which he has appended to his lecture, 'Eis und Gletscher'), the pressure on the previous plane or point of contact would be distributed over a larger space, with the thermal effect which can easily be deduced from the foregoing principles. In this way as the glacier-mass is diminished at the surface, a partially compensating formation of ice may go on at the base. So far as it acted, there would be a transfer of materials to some extent away from the bed. A little further reflection will show us, however, that this could only happen where the water was unconfined, and consequently only where the glacier was moving down a slope. In such a case the result would seem to be rather adverse to erosion. When however the glacier lies on a level or hollow surface, such a process must soon bring itself to an end; for, the glacier being motionless at the base, all spaces would soon be filled with ice and cold water kept there by gravitation, and the whole pressure would bear directly upon the rock, tending, not to break it up, but to compress it.

A word or two is needed on the influence of *terrestrial heat*. The facts connected with the flow of heat by slow conduction from the interior to the exterior of the earth's mass can be learnt from any good text-book of physics. The point with which we are here concerned is this:—Since the rock in contact with the ice remains at the same temperature as the ice, it can only do so by parting with its heat to the glacier as it receives it from below. This heat must do work. What is that work? Clearly the heat must be expended in overcoming the cohesion of ice-particles in contact with the rock. And this it would do whether the ice were at or below  $0^{\circ}\text{C}.$ , since in the latter case the heat received from the crust of the earth cooperates with the pressure which is the necessary condition of a temperature below  $0^{\circ}\text{C}.$  The bearing of this fact as tending to diminish friction, and therefore erosion, has been pointed out above\*.

In connexion with glaciers there is, in addition to the polishing, striating, and grooving work, observable everywhere on glaciated rocks, a still more extensive work of erosion going on, by the action of the *glacier-streams* which flow beneath them. Such streams, while they intervene in places between the ice-mass and the trough in which the glacier moves, are capable of doing much more work than the ice itself, by virtue of the greater velocity with which they carry stones and sand along. Since, however, this action depends entirely upon the movement of the water, it is clear that a descent is necessary for this movement; and as water does not flow up-hill,

\* The conduction downwards of absorbed solar heat from the sides of the valley to below the surface of the glacier produces in the summer a want of contact, for some feet down, between the ice and rock—a fact familiar to every observer of glaciers.

each glacier-stream must maintain an open channel for itself; for this reason the same objection applies to it as to a river flowing in an open valley, as an agent of excavation of basin-like hollows. Here and there, where we see the convergent surface-streams of the glacier rushing down the shaft of a *moulin*, and carrying from time to time earth and stones from the surface-moraines, a certain slight work of excavation is no doubt accomplished, such as we see now exposed to the light of day in the well-known "glacier-garden" at Lucerne; but this would hardly meet the requirements needed for the excavation of lake-basins. The main glacier-stream, just like any other stream, acts of course as an erosive agent and deepens the trough in which the glacier moves, an excellent example of which I observed only last summer at the end of the Hochjoch Glacier, at the head of the Rofen Thal, where the ice forms an arch resting upon the sides of the gorge as its buttresses.

Again it is undeniable that an advancing glacier may do a certain amount of "ploughing" work, such as Prof. Tyndall has described in connexion with the G6rner Glacier\*. This, however, is only evidence of the inability of the glacier-ice to move over the superficial obstacles which it encounters in its path; it would seem to tell rather against the notion of the ice being driven up-hill out of a basin, as is assumed by some writers; and it would be interesting to inquire whether such phenomena have ever been observed where a glacier was not descending a slope. All that has been put forward with reference to the distribution of the potential energy due to gravitation in the procession of the glacier down a valley must tell equally against the propulsion of it up-hill.

On the other hand, we may, I think, draw a distinction between the "ice plough" and what I may be allowed to call the "ice chisel."

In cases where successive portions of a glacier descend a vertical, or nearly vertical, precipice, a different set of mechanical conditions is presented to us. Impact may in this case perhaps do the work of excavation to such an extent as is represented in the excavation of many small rock-basins, such as some of those which lie upon the Bernina Pass, or at the foot of the precipices of Snowdon. But when all this is admitted we have no right to reason from "the hundreds of tarns that are found in all glaciated mountain-countries" to the formation of lake-basins which form long depressions in narrow valleys. Many tarns, however, do not occupy rock-basins at all; some are formed by moraine-heaps left by the retreated glaciers, between which and the mountain-side they may be frequently observed to lie in the Alps; other tarns simply fill depressions formed by earth-movements on the mountain-slope, where the clayey materials produced by the disintegration of hornblende, augitic, and felspathic *d6bris* get loosened by water and move unequally downwards, as clay often does on a smaller scale in a railway-cutting. Numerous instances of such could be pointed to in the Alps and in other mountain regions.

It is not without regret personally that I find myself driven to

\* Forms of Water.



conclusions adverse to the theory of excavation which has been advocated for some twenty years by Sir A. Ramsay, to whose geological writings we are all so greatly indebted.

### *General Conclusions.*

It will be seen from what has been advanced that I do not question the power of glaciers to do a good deal of surface-erosion in grinding, polishing, grooving, and striating the rocks; no one who has seen any thing of glaciers or of glaciation could do this for a moment. My contention, from the consideration of mechanical and physical principles, is that far too much work has been ascribed to them by some writers in the way of erosion, and that the notion of actual *excavation* of lake-basins is inadmissible, except under very special circumstances such as those under which some tarns may have been formed.

The causes of the differential movement of glaciers would appear to be three:—

(1) Cracking and partial melting in places under pressure and strain, followed by regelation, as propounded by Tyndall and accepted (after independent experimental investigation of the phenomena) by Helmholtz. This is probably the principal regular cause.

(2) Friction generating thermal energy, and so producing liquefaction, which is followed by regelation.

These two causes, it will be seen, are in constant operation, and *a fortiori* must have operated still more powerfully when the glaciers were of much greater dimensions.

(3) There remains to be accounted for a *secondary* differential motion, which has, it appears, not yet received a satisfactory explanation, though some recent writers have attempted it\*: the movement is greater (a) by day than by night, (b) in summer than in winter. This was very nearly explained some years ago by Canon Moseley, when he maintained that somehow or other 'radiant heat' must enter the ice. Had he known those principles of physics which are illustrated by the action of Crookes's radiometer, there is little doubt that he would have seen his way to the right explanation. The theory which I venture here to advance is based upon a series of experiments with ice subjected to different sources of radiant energy, in which I have been engaged, an account of which I hope to publish elsewhere†. For the present purpose we must consider *heat* to mean energy capable of melting ice or tending to melt it. Whatever notion we may attach to the term "radiant heat," it is clear to me from my experiments that heat, *qua* heat, cannot enter the ice and be afterwards expended in the work of liquefaction—that is to say, in overcoming cohesion and so promoting differential movements of parts of the glacier. All such heat must become latent in the liquefaction of ice at the surface. It is in the *transformation of energy* that the clue is to be

\* See Croll, 'Climate and Time,' chap. xxxi.

† See Nature, No. 693.



found. To say that ice is transparent is to say that *luminous radiant energy* can freely traverse it. It does not do so however equally at all times. Obviously, more luminous energy enters the glacier from the sun by day than by night—more during the more numerous hours of daylight, the higher ascension of the sun, and the greater freedom from the diffusive action of the snow at the surface in summer than in winter. A certain amount of the luminous portion of a beam of solar radiation is absorbed by even clean ice, more especially by granular ice, otherwise the beautiful silvery blue colour which is perceived in the ice overhead when one enters an ice-cavern would be wanting. But it is chiefly by opaque and semi-opaque bodies within the glacier (stones, earth, organic germs, &c.) that the luminous solar radiation which enters the ice is absorbed; and the radiation thus absorbed is, in accordance with the law of conservation of energy, converted into heat, just in the same way as it is in an ordinary greenhouse. Heat thus developed within the mass of the glacier, during the hours of daylight, and most so during the summer, must promote the differential movement of the glacier. Of course, if the glacier is clean enough and thin enough, some of the luminous energy may penetrate to the rocks beneath; but the transformation of energy would in that case be the same, the heat developed promoting the descent of the glacier as a whole, instead of its differential motion.

#### DISCUSSION.

Mr. CALLARD stated that in 1878 he had had the opportunity of studying the base of the Rhone glacier, which glacier has been slowly receding for a length of time. Beneath the glacier, as seen in the terminal ice-cave, the ground was not ploughed but only somewhat smoothed.

Prof. SEELEY pointed out that before we could accept the author's views it would be necessary for him to explain the origin of the quantity of detritus carried out from the end of the glacier and the smoothed surfaces on the bottom and sides of the glacier-bed. He thought that the effect of the continual melting and freezing of water at the bottom of the glacier on the rock masses below had been overlooked by the author, and that these effects must be very striking. The late Mr. Clifton Ward had shown that some lake-basins occur at the point where tributary glaciers join the principal ones.

Mr. BLANFORD referred to the *à priori* argument, based on the fact that rock-bound lake-basins abound in districts which have been glaciated, and are rare in other regions. He pointed out that the author seemed to have lost sight of the fact that the erosion was performed not by ice but by stones &c. held in the ice.

Lieut.-Col. H. H. GODWIN-AUSTEN said that the great glaciers of the Himalayas, which are so much larger than those of the Alps, are advancing, breaking away the ground along their sides, and pushing forward their older moraines. It must also be remembered that glaciers of the great thickness of the older glaciers in Switzerland must have produced very different effects on rocks of

different degrees of hardness, and that thus rock-basins might have been produced.

Mr. WALTER BROWNE agreed with previous speakers that the fact that the rivers flowing from the ends of glaciers contain so much mud is proof positive that they erode their beds. He had seen the G3rner glacier pushing the turf of fields before it like a plough. He called attention to considerations laid before the Royal Society in his recent paper, especially that the Greenland glaciers move, in the depth of winter, at temperatures far below 0° C.; and he thought this fatal to the movement of glaciers being due to regelation. According to the author's theory, glaciers would cease to move when they reach a horizontal surface.

Dr. HICKS thought that the author had proved his case, which was, that ice, by itself, cannot erode rock-surfaces.

Dr. WOODWARD referred to the observations of Dr. Hector, in New Zealand, and said that no glaciers are absolutely clean, but all contain rock fragments, consequently all glaciers are capable of erosive action.

Mr. BAUERMAN objected to the author's comparison of ice and glass. Ice is perfectly crystalline, as shown when examined by polarized light, the principal axis of the crystals being perpendicular to the planes of cooling. Apart from this point, he was inclined to agree with the conclusions of the author. He did not think there were any experiments which could be quoted in support of the view that glaciers can erode rock-basins. He thought that what is usually called glacier-erosion would be found to be due to the erosion of water in confined channels beneath the glacier.

The Rev. E. HILL said that the argument that the thrust was mainly expended in overcoming cohesion rather told against the author's views than supported them, as the friction of the sides of the glacier is necessary to produce a resistance to the thrust.

The Rev. E. S. DEWICK agreed with Mr. Bauerman's views on the subject.

The AUTHOR said that, in the remarks objected to by Mr. Hill, he had been merely arguing against the view that the glacier moves as a solid mass. He fully recognized the "filing" action of the stones held in the ice; but since these stones and the rocks they grind against are of *equal hardness*, only at most one half of the pulverized material brought away by the glacier-stream comes from the rocks over which the glacier moves. He agreed with Mr. Bauerman as to the work done by streams beneath the glacier, and had given an illustration of it in the paper. He argued, not against the erosive power of glaciers, but against their power of cutting rock-basins such as those occupied by lakes. He had already met many of the objections raised to his views in a paper to be read in a fortnight's time. He had pointed out one cause of the motion of glaciers which is quite independent of climatal conditions, namely the conduction of heat to the glacier from below. The surface-conditions in a region of *excessive radiation* like Siberia, which Mr. Browne had referred to, were not comparable with the conditions found beneath the glaciers in Greenland.

7. *On the ORIGIN of VALLEY-LAKES, with especial reference to the LAKES of the NORTHERN ALPS.* By the Rev. A. IRVING, B.A., B.Sc., F.G.S. (Read, December 20, 1882.)

THIS paper is intended as nothing more than a supplement to a paper by the author on the Mechanics of Glaciers. The main strength of the position taken up by the advocates of the glacier-excavation theory is derived from arguments which labour to show that it is the only feasible hypothesis\*. I have endeavoured to show in my previous paper that this hypothesis is inadmissible on mechanical and physical grounds; all I attempt to do here is to show that we are not shut up to the hypothesis; for many agencies can be pointed to which may have cooperated to form lake-basins, some of which have hardly been considered with sufficient care, while others would appear to have been ignored. In dealing more especially with the lakes of the Northern Alps, I have simply selected a region which abounds in lakes occupying expansions of river-valleys which I know pretty intimately from direct observation, including a district already treated more in detail by Prof. Bonney†. Nor do I pretend either that all which is here advanced is new to geology, or that I am able to give an exhaustive account of all the agencies which have helped to form lake-basins past and present. Many lakes also, for example such as those which occupy the craters of extinct volcanoes in the Eifel and elsewhere, are excluded from consideration here by the title of the paper.

I shall first draw attention to what appear to me defects in the arguments of the excavationists, as propounded by Sir A. Ramsay himself, by which they would shut us up to the "excavation hypothesis."

1. With reference to these Alpine lakes, the position of some of them is very difficult to account for if they were excavated by the great glaciers which, during the Glacial Epoch, moved mainly from the central chain of the Alps towards the low-lying country.

The position, for example, of such lakes as Neuchâtel, the Bodensee, the Wallensee, the main portion of the Vierwaldstättersee, and the lakes lying in the Traun valley above Aussee would be very difficult to explain in this way, especially if we take into account also the contours of their basins. Seeing the thing in three dimensions, as in nature, gives a truer idea than the representation of it in two dimensions only, as on a map.

2. The argument against lakes lying in valleys formed by *synclinal* folds of the strata, so far as it goes, seems to overlook altogether the frequent occurrence of valleys lying along the axes of

\* *Vide* Prof. Ramsay's paper, Quart. Journ. Geol. Soc. 1862. The arguments put forward in this paper have been recently summarized by Sir A. Ramsay in his 'Physical Geology and Geography of Great Britain,' 1878.

† Quart. Journ. Geol. Soc. vol. xxix. p. 382.



*anticlinal* flexures. Such valleys occur very frequently in the Alps and elsewhere. Von Hauer\* has given us an idealized section across the North-eastern Alps, representing the repeated occurrence of this phenomenon among the Secondary (chiefly Triassic) strata; and I could furnish instance after instance from my own note-book in verification of his generalization. A capital instance of a line of valley thus placed with reference to a great line of anticlinal fracture, though quite subordinated to the main anticlinal of the whole Alpine chain, has been described by me elsewhere†. All such valleys have of course been widened and deepened by the erosive action of running water; but it is difficult to conceive of their initiation in any other way than by open fissures, since otherwise the flow of water must have taken place along an elevated ridge, which is absurd. Fracture, therefore, has played a part in the production of some valleys; and if so, it may have had something to do with the formation of any lake-basins which occur in such valleys.

3. The argument drawn from the fact (which every one will be ready to admit) that lines of dislocation produced in highly metamorphosed strata must have appeared as closed lines when such strata were first laid bare by denudation, does not apply universally. It fails utterly when applied to the region with which we are especially dealing; these valley-lakes do not occur among such strata, but among well-stratified rocks of Secondary and Tertiary age. Nor is it fair to reason from the close faults which occur among the comparatively undisturbed strata of Secondary age in England, where lakes do not occur, as to what can or cannot occur among the highly disturbed and contorted strata of the Alps, where valley-lakes abound. The force of this argument will be fully appreciated only by those who know pretty intimately those portions of the Alps to which I now refer; seeing with one's own eyes carries more conviction on this and many other points in geology than mere book-knowledge can do. In some cases disturbance and dislocation of strata have gone to such an extent as to invert the original order in which the strata were deposited. A conspicuous instance of this sort of thing occurs in North Tyrol, which was described some years ago by Richthofen, and has since been more fully described by Gümbel‡. Between Weissenbach and Vils the strata have been thrown into a sharp anticlinal, accompanied by inversion, so that strata of Jurassic age are found now underneath strata of the age of the lowest Trias. In the immediate proximity was once formed an extensive lake, studded with numerous islets, perhaps once the most beautiful lake ever produced among the Alps, though now filled up by the alluvial detritus of the river Lech and its affluents. On this stands the thriving modern town of Reutte. Again, inversion of a similar nature has taken place about the Rigi, in close proximity to the Lake of Lucerne, as Sir. A. Ramsay pointed out long ago§. May not both these lakes be connected with fractures

\* Die Geologie, fig. 251.

† Vide Geol. Mag. Nov. 1882.

‡ Vide Von Hauer's 'Die Geologie,' pp. 366, 377, and fig. 254.

§ Quart. Journ. Geol. Soc. 1862.



and hollows formed by those movements which produced the inversions here alluded to?

4. The theory of *subsidence* has had but scant justice done to it. Alpine geology opens one's eyes to the importance of this in a way that English geology does not; it is not enough therefore to dismiss this subject on the negative grounds that in England we have nothing more than mere pools formed in this way, where the solution and removal of the salt-beds beneath has led to subsidence. Nor do I see any force in the argument against the theory from the mere number of instances. No one would maintain that all the lakes even of the Northern Alps are due to subsidences; the point is that here we do find *conditions favourable to subsidence extending over hundreds of miles in a district abounding in lakes*. The materials of which the mountains are composed are for the most part calcareous and dolomitic in character, the strata being often almost pure limestone or dolomite. There is no necessity for explaining here how underground erosion is carried on by water in such strata; the fact is well known, as in the case of the famous caverns of Castleton and Adelsberg, to mention only two most conspicuous instances. Again, in this very region beds of rock-salt and gypsum abound, some of them of great dimensions. The lateral outflow from the Königsee through a hole in the mountain, the water passing for miles underground and issuing again as a river in the direction of Hallein, serves very well to illustrate the way in which the waters which have done the work of underground erosion can find their way from these upland valleys, in which most of the lakes we are considering occur, down to lower levels. In some instances the actual amount of material carried from the interior of the mountains has been found to be astonishingly large. I shall mention here two examples given by Credner\*:—(a) At Neusalzwerk, in Westphalia, it has been found that the brine-springs of that district bring to the surface 376 cubic metres of carbonate of lime annually; (b) In the Visp-Thal, in Canton Wallis, a series of 'Erdfälle' accompanied by small earthquakes continued for a whole month in the year 1855, due to the undermining of the valley by the removal of gypsum in solution. The district contains some 20 gypsiferous springs, one of which alone brings to the surface over 200 cubic metres of gypsum per annum. Such facts enable us to realize more vividly than any thing which English geology presents to us the importance of underground erosion as a geological factor.

It is the mere enunciation of an axiom to point out that in all such cases the materials cannot at the same time be removed from the interior of the mountains and remain inside them. Time is the most important factor in such cases. The prevalence of salt and of brine-springs in those northern Alpine regions where the lakes are most numerous is recorded in the frequent occurrence of local names indicative of their presence (*e. g.* Salzburg, Hallein, Hallstadt); and an exploration of any of the salt-mines of the district opens one's eyes to the great extent to which underground excavation has been

\* Elemente der Geologie, pp. 207, 210.

carried by mere solution within a few centuries only. It is somewhat incomprehensible to me that the significance of the fact that so many of the valley-lakes of the northern Alps lie among strata where conditions specially favourable to subsidence are found, has been so much overlooked by writers in this country. The subject will be found more fully treated in the excellent text-book of Credner, who (p. 211) mentions the Königsee as a special instance of a lake most likely formed by subsidence. The evidence is indirect but strong.

Here we are led to the recognition of another agent which, so far as I know, has not been before specified as promoting subsidence. It has been pointed out by Credner that the conversion of anhydrite into gypsum by taking up water of crystallization, breaks up a valley-floor under which the more massive beds may have been removed by solution, and thus promotes subsidence. But I am not aware that it has ever been before pointed out that, where underground erosion from either of the causes mentioned had taken place in pre-glacial times beneath the floor of a valley (the natural operations which go on now having gone on then), *the dead weight of the enormous glaciers \* which filled valleys thus undermined may have crushed in their floors.* For such reasons I think that the suggestion of Playfair that the bed of the Lake of Geneva had sunk owing to underground erosion, deserves more attention than it has received.

The connexion between the frequent occurrence of lakes and limestone regions becomes more important when we consider the relative numbers of lakes in such regions and among the crystalline rocks. Something like 100 lakes may be counted (large and small) among the stratified deposits of the Alps, while I do not think a dozen (if we exclude mere tarns) could be pointed out as lying among the crystalline rocks. And if we extend this examination to other parts of the earth's surface, we find a similar rule holds good in Ireland (where the lakes occur for the most part in the Carboniferous Limestone), in the Apennines, in the region of the Middle Danube, in the Balkan peninsula, and in Asia Minor.

Again, it is possible, reasoning from what we know of solution of the chalk strata at the surface in England by rain-water holding  $\text{CO}_2$  in solution, to see how, in some cases, lakes once formed among limestone mountains may have been deepened by a process of chemical solution. The long exposure of the snow which, on melting, feeds many of these lakes, and the mechanical division of the water during its descent into them from the mountains, are both circumstances favourable to the saturation of the water which enters the lakes with the gases of the atmosphere. So far as this cause operates, it tends to deepen a lake, though it could only do so effectually in a case where the quantity of detritus carried into the lake was exceptionally small.

*Other Lake-forming Agencies.*—(1.) It is clear that any cause which leads to a change in the contour of a valley of erosion by distur-

\* Such as that of the Etsch-Thal, which filled the valley up to about 1500 metres (Credner, *ibid.* p. 663).

bance of the strata of the region may produce such alterations in the relative levels of different parts of the valley as to bring the floor of the valley at some points to a higher level than the floor of the valley nearer to its head. It is no drawing upon the imagination to say that such movements have occurred on a large scale in the Alps since the older lines of valley were eroded by water-action. To mention one fact only, the changes of level of the European continent which brought the shores of the continent so far south as to allow the southerly drifting icebergs from Scandinavia to deposit their erratic blocks as far inland as Bonn, Westphalia, Thuringia, Saxony, and Moscow\* could hardly have happened during Quaternary times, and been reversed, without some considerable squeezing and consequent disturbances of the strata of the Alps, such as we observe today on such a gigantic scale.

I take it, then, that many of the lines of flexure which have been before referred to as abounding in the stratified Alpine deposits are of comparatively recent date. The effect of such lines of flexure occurring transversely to the older lines of valley-erosion would be to form hollows, which must get filled with water from the surface-drainage of the valley. This has been already pointed out by Prof. Bonney†; and I may perhaps illustrate the principle more fully than he has done from the example of the Lake of Hallstadt. This beautiful lake lies in a north-to-south valley, and is one of some half a dozen lakes which lie in the line of the river Traun. The stratigraphy of the Hallstadt basin may be understood readily from the accompanying sketch (p. 78), which was made on the spot, not from a cursory glance, but during a stay of more than a fortnight in the vicinity of Hallstadt. It of course represents the face of the mountain on the western side of the lake. The strata of the Sarstein massif on the eastern side show a corresponding *synclinal* arrangement. The line of anticlinal flexure, which is recorded in the dip of the strata from the Gosau Schlucht, having been formed in comparatively recent times, has produced so much of the Hallstadt lake as lies in a true rock-basin. The lake owes, however, a considerable portion of its depth to the diluvial detritus which has been brought into the Traun valley from a valley on the eastern side, and has dammed up the valley from Steg in the direction towards Ischl. The section represents a thickness of strata of over 4000 feet, entirely of Triassic age. About midway between the two gorges the strata above the pine-forests are highly contorted; and beyond them lie the contorted upper Dachstein strata.

It is worthy of remark that such changes of level as are here referred to are not so distinctly recorded as are many similar changes which are known to have occurred in mountain-regions contiguous to the sea (*e. g.* in Norway, in South America, and in New Zealand), where the mean sea-level serves as a datum-line from which to estimate their extent‡.

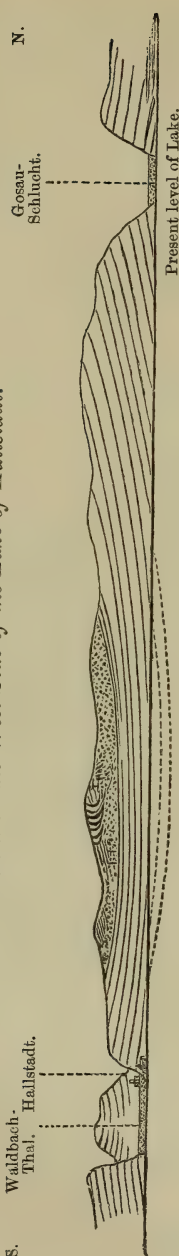
\* Credner, *El. der Geol.* p. 651.

† *Quart. Journ. Geol. Soc.* vol. xxix.

‡ *Vide Credner, ibid.* pp. 169, 170.



Section on the West Side of the Lake of Hallstadt.



(2) Again, it may well have happened that in some of these later movements of the mountains, *lateral thrusts* may have acted vertically, or nearly so, to older lines of valley. The effect of such forces would be, if the resultant force was not too deeply seated, to partly close in the valleys upon which they were brought to bear, until the sides of the valleys in their narrowest parts came together, leaving the wider portions to form true rock-basins, which, getting filled with water from the surface-drainage, would, of course, form lakes. The direction of the principal lines of flexure of the Jura chain affords a strong presumption in favour of the hypothesis that in this way the valley of the Rhone below Geneva may have been partly closed in. This alone would account for so much of that lake as lies in a true rock-basin. Part of its depth, however, it owes to the delta of the Arve, which has been brought down from the Mont-Blanc region\*.

(3) There is a phenomenon† well known to mining-engineers as a "creep." In old coal-workings it is found that the vertical pressure of the superincumbent strata, acting upon the strata immediately below the galleries where the coal-seams have been removed, causes the floor of the mine to rise, so as in time to completely fill up the disused workings. Such a resolution of vertical pressure is possible where more massive strata, as often occurs in the lake-regions of the Alps, rest upon strata of a more yielding nature on opposite sides of a gorge-like valley. In such cases the erosion of the valley being continued down to the lower strata, these, being at the

\* *Vide* 'Les Causes actuelles en Géologie,' by Meunier, pp. 203, 204.

† *Vide* Lyell, 'Student's Elements,' p. 56.



same time made more accessible to the surface-water and consequently rendered more yielding, might very well be elevated in places where the mechanical action of the valley-stream was too sluggish to enable it to wholly counteract any upthrust by the deepening of its own channel. In this way I conceive that some of the smaller valley-lakes may have been formed.

(4) Some valleys occupy lines of *faulted dislocation*—such, for example, as that which runs northward from the Inn Thal, and coincides with the gorge of Jenbach and the Achen Thal. The evidence, which I recorded on the spot during three ascents of the surrounding mountains, and which has been given by me elsewhere\*, is confirmed by a reference to Von Hauer's map of Tyrol. In this line, at nearly its highest part, lies the Achensee, the greatest depth of which (2500 feet) is said to be just off the eastern shore. Here is a connexion of a lake with a fault.

(5) The function of *moraines* in forming dams across valleys is too well known to require that I should occupy much space here with the consideration of it. As, however, one's acquaintance with the Alps increases, one is greatly impressed with the frequency of such occurrences, notable examples of which occur in the Oetz-Thal, in the cases of the Obersee and Töplitsee, and many others which might be mentioned, where a terminal moraine has blocked up the valley. In some cases, as with L. Garda† and the L. of Llanberis, such moraine-material would appear to have been redistributed, and so partly stratified by marine action. Credner‡ has already pointed to the connexion of the outlying lakes of the Alpine region in S. Bavaria—the Ammersee, Starnbergersee, and Chiemsee—with moraines. Huge lateral moraines, left by the glaciers on the sides of valleys, such as may be observed at the head of the Rofen Thal below the Hospiz, and at Carthaus in the Schnalser Thal, may descend and block up a valley if once permeated by water, which increases its weight and at the same time diminishes the internal friction of its materials as well as their friction against the mountain-side. Such a movement of a great moraine is now actually going on at Fetar, in the Unter-Engadin§.

(6) The last point leads to the consideration of *Bergstürze*, of which there are some notable instances, *e.g.* the formation of L. d'Alleghe and L. Derborence during the last century only, and the catastrophes of Goldau and Elm within the present century. The extent of the part which these have played in Alpine physiography can only be faintly understood from what is observable in such worn-down stumps of more ancient mountains as we meet with in Wales, Cumberland, and Scotland. "We find," says Heim, "no Alpine valley without such heaps of mountain *débris* and traditions having reference to them. A still older series belongs to a time extending far back beyond the range even of tradition. The largest and, perhaps, the oldest we can recognize is that of

\* Geol. Mag. Nov. 1882. "The Triassic Deposits of the Alps."

† Cf. Mr. John Ball, F.R.S., Phil. Mag. 1863, vol. xxvi. p. 499.

‡ Elem. d. Geol. p. 663. § Vide Heim, 'Ueber Bergstürze.'

Flims, in Graubünden. It forms a mountain 600 metres high, and extends from near Ilanz to Reichenau, in the Vorder-Rhein Thal. Upon its surface eight small lakes are found. The Rhine and its tributary streams have sawn it out into a number of hills which abut as spurs upon the valley; and at the present time above Ilanz there are still *visible traces of the ancient lake* which was formed by the waters of the Rhine as the valley was blocked up by the Felssturz of Flims. Upon the back of this huge mountain of *débris* there are traces of glacier-moraines and enormous blocks from the Puntaiglas Thal. This Bergsturz is therefore older than the period at which the moraine-materials were spread upon it—that is, older than the glacial period.” A few smaller lakes formed by Bergstürze were observed by me last summer near the Firn Pass in Tyrol; but I am not aware that they have been yet described anywhere.

(7) Lastly, there is the action of *diluvium* in blocking up valleys. This fact must be so familiar to all Alpine travellers as to need no proof here. In many cases the materials have been more widely distributed, so as to form alluvial deltas, of which I have noted a score or two of instances, at points where two valleys converge. In other cases the diluvial detritus remains piled up in huge chaotic masses at the mouth of a gorge opening laterally into a valley. I saw such a recent accumulation only last summer, near Sölden, in the Oetz Thal; and Credner\* relates an instance which happened in the year 1818, in the Bainen Thal, in which a mass of *débris* 100 metres high was accumulated at the mouth of the gorge, some of the transported blocks of granite measuring 40 cubic metres. Sudden and great downpours of rain in Alpine regions, or the rapid melting of snow by the warm dry wind known as the Föhn, may furnish the rushing waters. Collected from an extensive and steeply sloping basin high in the mountains, and driven with enormous velocity downwards, as through the narrow neck of a funnel, the transporting power of water becomes enormous, while the rock-materials, being only generally of a specific gravity of 2·00 to 2·90, lose nearly one half of their weight in water. As soon as such a powerful current escapes from the confines of its narrow channel, its velocity of forward movement is again diminished, and it deposits its burden near the mouth of the gorge as chaotic masses of stones or as mud-streams. In time all the smaller stones and earth get spread out as deltas, which in numerous cases are seen protruding into lakes already formed, and in some instances have actually divided a lake into two, as is the case with the Plansee, and with the more notable instance of Lakes Brienz and Thun. Some instances of enormous work done in this way, as the result of a single storm, have come under my own observation. The side valleys which pour their water and rock-*débris* in this way into another valley are often of younger date than the principal valley: they may be seen in all stages of recession from older valleys in the Alps. Difference of composition and the strike of the strata may also help to forward disintegration along some lines rather than along others. The one

\* Elem. d. Geol. p. 222.

essential point in connexion with diluvial accumulations is the fact, which can be verified over and over again, that the lakes at the outflow of which such accumulations are found, lie above the point of convergence of two valleys. It is for the advocates of the theory of glacial excavation to show why the work of excavation was *not* done where the union of two glaciers should have been capable of doing the greatest amount of work.

We may define a lake as *a hollow in the surface of the earth, which is so placed in relation both to the superficial and underground drainage of the district in which it is situated, that it is filled with water, either to the lowest point or points of overflow, or to such a mean level as corresponds with the excess of the mean annual precipitation over the mean annual evaporation of the district in which it lies.* This is about as much as can be asserted generally of lakes; and it is impossible to give any general rule as to the formation of their basins. Each basin must be worked out as it is, in relation to all the geological, cosmical, hydrographical, and other conditions which bear upon its existence. The hypothesis of the glacial excavation of lake-basins is not only irreconcilable with the known physical properties of ice; it is, besides, unnecessary, since lake-basins can be accounted for without it.

#### DISCUSSION.

Mr. W. R. BROWNE suggested that a lake would be emptied by a slight tilt in the general slope of the country; and a corresponding diminution in the slope would form the lake. Wastwater would require as much as one in twelve. This change, which would only be one in fifty for the Lake of Como, and one in ninety for the Lake of Geneva, might well have taken place in the various alterations which have happened in times since denudation had commenced. The elevation of the central part of the chain would tend also to increase the glaciers.

Prof. BLAKE stated that there were many causes for lakes, and that those mentioned by Mr. Irving were familiar to geologists. The main question is, Can a glacier ever excavate a lake-basin? If that could be made clear, some progress would be made. He did not think it was proved that glaciers could not excavate lakes. From the shape of the sides of glacier-valleys, there must be most erosion at the bottom. If the medial moraines are brought up from the bottom, so might the excavated material be. The lakes of Neuchâtel and Constance were difficult to explain as eroded by glaciers. It was singular that, as the Lake of Geneva had been filled with ice, Miocene fishes should still be found in it.

Mr. A. TYLOR had proved by experiment that ice has erosive power. The velocity increases as the cube-root of the mass; and the erosive power augments in a high ratio with the velocity. Multiplying the present mass of a glacier by 64 would increase its velocity by 4, and its erosive power by at least 200. This he had



pointed out in the 'Geological Magazine' for 1875. In lake-glaciers motion is chiefly derived from the expansion of ice in the act of freezing. The water produced by the heat developed by friction during the progress of the glacier freezes in the glacier and causes motion (in the direction of the least resistance) towards the outlet of the lake where the glacier is thinnest.

Mr. TEALL said the burden of proof must rest with those who asserted that a glacier could excavate. The differential motion of a glacier was a most important point. If the ice were moving up-hill it would be stopped by friction and gravitation; hence it was difficult to understand how a basin could be excavated, and very strong proof was needed.

Prof. BONNEY criticised Mr. Tylor's section and idea, and stated that, while agreeing with Mr. Irving in his general principles, he differed as to the details. He thought that Mr. Irving had not allowed for the fact that many of the large lakes lay in true basins, so that he could not explain them by moraines or *débris*. Still he thought that rock-movements accounted for the larger basins.

Mr. W. MATHEWS referred to the recession of the Swiss glaciers during the last few years, and asked if on any rock thus exposed a basin had been seen.

The AUTHOR, in reply to Prof. Blake, referred to the last discussion and his last paper. He entirely dissented from Mr. Tylor's view of the possibility of the ice doing erosive work by freezing at the base of the glacier; it would have to expand under great pressure, and so would compress and solidify rather than erode the rocky floor. The question of how much of a lake was true rock-basin and how much formed by moraine or detritus must be worked out in each case separately.



8. *The DRIFT-BEDS of the NORTH-WEST of ENGLAND and NORTH WALES.*—*Part II. Their NATURE, STRATIGRAPHY, and DISTRIBUTION.* By T. MELLARD READE, Esq., C.E., F.G.S. (Read November 15, 1882.)

[PLATE V.]

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INTRODUCTION.

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" " " Ribble.

" Coast from Blackpool to St. Bees.

" North Coast and Mountain-district of North Wales.

CLASSIFICATION AND CONCLUSIONS.

Pre-drift Surface of the Land.

Red Sand and Rubble *débris* of the Trias.

Gully-gravels.

Low-level Boulder-clay and Sands.

Mountain- and Hill-Drift.

Conclusion.

INTRODUCTION.

IN Part I. of this paper, devoted to the "Shells of the Lancashire and Cheshire Low-level Boulder-clay and Sands"\*, read before this Society in 1873, I discussed in outline some of the physical problems involved in a correct interpretation of the phenomena of the Drift as it is exhibited in Lancashire and Cheshire.

It is now my intention, by the aid of numerous sections I have been more or less continuously recording before and since that time, together with observations in other parts of England and in Ireland, Scotland, and Wales, to redraw my picture with a firmer hand. This delineation of the Glacial period in the north-west of England will rest almost entirely upon my personal observations; but, at the same time, I shall not neglect those important additions to our knowledge contained in the Geological Survey memoir by Mr. C. E. De Rance, F.G.S.†, or the valuable papers by that untiring observer Mr. Mackintosh, F.G.S.‡, by Mr. Shone, F.G.S.§, the late Mr. Binney, F.R.S., and others by Messrs. Tiddeman, Goodchild, and the late Rev. Clifton Ward, published at various times in the Quarterly Journal of this Society. Neither will the more general papers by

\* Quart. Journ. Geol. Soc. February 1874, vol. xxx. pp. 27–37.

† Superficial Geology of South-west Lancashire.

‡ "High-level Shelly Deposits of the Eastern Slopes of the Welsh Mountains," Quart. Journ. Geol. Soc. vol. xxxvii. 1881, pp. 351–369.

§ "Dispersion of Erratics of West of England and East of Wales," Quart. Journ. Geol. Soc. vol. xxxv. 1879, pp. 425–453.

§ "Glacial Deposits of West Cheshire," Quart. Journ. Geol. Soc. vol. xxxiv. p. 383.

Mr. Searles Wood, jun., F.G.S.\*, nor the work of Dr. James Geikie, F.R.S.†, be neglected where they bear upon the subject in hand and lend any help towards unravelling this most complicated and difficult problem.

### RIVER-BASINS.

To describe in a manner that can be realized the distribution of the Drift-deposits, it will be necessary to divide the country treated of into local areas. The most natural division that suggests itself to me is that of river-basins; for, as will be seen further on, the nature of the rocks occurring in these drainage-areas profoundly affects the character of the Drift distributed in them.

#### DRIFTS OF THE BASIN OF THE RIVER MERSEY.

In a communication to the Liverpool Geological Society in January 1873, entitled "The buried Valley of the Mersey," I showed by a careful comparison of a number of borings, well-sinkings, and excavations between Warrington and Liverpool that, buried and obscured by drift, there exists a rocky valley, probably Preglacial, the bed of which at Warrington Bridge is about on a level with the present bed of the river at Wallasey Pool, about 26 miles further down. This gorge does not pass Runcorn in the line of the present river, but cuts across the low-lying land upon which the town of Widnes is now built. At this point its greatest depth is 76 feet below the present bed of the river at Wallasey Pool. From data detailed in that paper I also inferred that a gorge most probably exists in the bed of the river between Liverpool and Birkenhead of a still greater depth. Since the above paper was written I have had opportunities of examining the excavations at the North Docks; and here, again, a system of lateral rocky gullies buried in drift was disclosed, one of which, filled with shingle and gravel under a coating of Boulder-clay, was excavated 40 feet below ordnance datum and further tested with an iron rod to a depth of fifty-two feet below ordnance datum without being bottomed‡. And, further, I see from the Report in 1880 of Vice-Admiral Spratt, the acting Conservator of the river, that borings undertaken by Mr. George Hill, C.E., for the Upper-Mersey Navigation Commissioners, show that between Weston Point and Hale Head there exists a deep depression. In Mr. Hill's words, "The most unexpected feature revealed by the borings is the existence of a deep depression in the underlying rock about the centre of the river, the sides of which appear in some parts to be precipitous;" "the rock in the depression is from 10 to 20 feet below the rock adjoining on either side, or from 20 to 30 feet below the Old-Dock sill"§.

This depression is hardly deep enough to have formed the main channel; it may have been one of the tributaries; and such an

\* "The Newer Pliocene Period in England," *Quart. Journ. Geol. Soc.* vol. xxxvi. pp. 457-527.

† The Great Ice Age.

‡ See article by me in the 'Builder' on the Mersey Tunnel, February 4th 1882.

§ The Old-Dock sill is 4.25 feet below ordnance datum.

occurrence is what my previous investigations would have led me to expect.

A boring for water at Burscough-Bridge Station shows the rock to be there 228 feet below ordnance datum, and to have 278 feet of drift, mostly sand and gravel, with some Boulder-clay beds, lying upon it. Thus there is progressive declination in the rock-level from Warrington towards the mouth of the Ribble.

*Drift in the neighbourhood of Liverpool and on the Lancashire side of the River Mersey.*

The Boulder-clay in the neighbourhood of Liverpool, though largely used for brick-making, is not a brick-clay in the same sense as the Clyde laminated clays. It contains many stones and in some places a good deal of limestone, which is apt to burst the brick when exposed to the weather after being calcined by the burning. In some cases the clay is passed through a machine to crush the stones. In places there are considerable depths of a fine unctuous clay, which has hitherto been considered unfit for brick-making; but the New Ferry Brick and Tile Company have proved this to be an old-fashioned delusion, as they produce much more perfect bricks than the ordinary Lancashire or Cheshire make, and even tiles, with a very fine clay belonging to this series.

I have touched upon the economical aspect of the question, as it enables a stranger much better to realize the geological nature of the clays.

In this clay and underlying it, as I shall presently describe, are beds of sand and gravel.

They rarely show at the surface in the district delineated; but sand beds are common in some other areas, and replace the Boulder-clay as a surface-deposit.

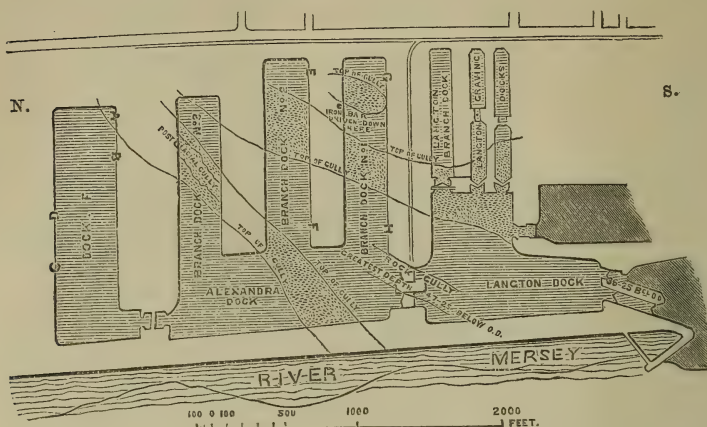
In my descriptions I do not propose to use the terms "Upper" and "Lower" Boulder-clay and "Middle Sands and Gravels" as I consider these titles beg the question which it is my purpose to discuss.

*Sections exposed in the North Docks at Bootle (fig. 1).*—Excavations for the Huskisson Branch Dock in 1872 showed the old shore-line of the river, consisting of silty gravels (with recent shells) from 1 ft. 6 in. to 2 feet thick, buried below the spoil filled in to form what was the Dock quay. The shore-line had been cut in the Boulder-clay, which was 24 feet thick at the deepest part, and consisted of an extremely homogeneous plastic clay containing occasional rounded pebbles and a few of the usual erratics. Beneath the clay was a bed of gravel from 2 ft. 6 in. to 3 ft. 6 in. thick, resting on red sand which covered the rock.

The rock-surface would therefore be about from 12 to 14 feet below ordnance datum.

A few irregular patches of sand occurred in the clay; but they were devoid of form or stratification.

In June 1874 I examined the excavations for the new Alexandra

Fig. 1.—*Plan of Atlantic Docks, Liverpool, 1874–81.*

Branch Dock No. 3; and here the Boulder-clay was again exposed. In the trench for the dock-wall parallel with the river-wall the surface of the Boulder-clay was 16 feet below ordnance datum. The section disclosed 9 feet of Boulder-clay, 3 feet of sand occasionally developing into gravel, and then from 3 to 5 feet of Boulder-clay resting on red sand and red "roach" rock.

A Postglacial gully excavated in the Boulder-clay intersected the dock; and in this was the trunk of an oak tree, about 3 feet in diameter, lying longitudinally in the gully, as if it had been washed down it, at a level of about 22 feet below high water; a layer of recent silt covered the whole.

In May 1876 further excavations showed below the silt a considerable thickness of peaty matter full of drift timber, principally oak and pine. In one place only, at the base of the peat, I observed the stump of a tree rooted into sand resting upon the Boulder-clay.

At various times between 1876 and 1878 I carefully examined the excavations of the series of docks and graving-docks, extending over an area of about 80 acres, and made record sections of the beds disclosed: these I reproduce (figs. 2–5, p. 88), as they will serve to explain the drift-geology better than any written description\*.

It must be understood that the beds are so irregular that another observer coming at a time when a different face was exposed would no doubt give a different representation of it. The sections I give I considered typical; and I vouch for their accuracy.

Speaking generally, the same succession prevails as occurred in the sections already described. In ascending order we have the red rock of the Trias with the red sand and rubble covering it; upon

\* I must here express my indebtedness to Mr. G. F. Lyster, the engineer to the Mersey Docks and Harbour Board, for the facilities of inspection afforded me and for much information given.



this lies the shingle or gravel ; but sometimes the Boulder-clay lies directly on the rock, and in other cases the shingle is divided by patches of Boulder-clay. At another point the gravel is entered by a sand seam which divides the Boulder-clay where the deposit becomes thicker in consequence of depressions in the surface of the rock on which it rests.

The lower part of the clay may be described as containing more waterworn boulders than the upper, thus partaking of the nature of the shingle it is in contact with. The upper part of the clay is more plastic, like that of the Huskisson Branch Dock, but contains, usually, large and numerous glaciated erratics of granite, dolerite, diorite, limestone &c., some of which must weigh several tons.

In November 1881 I made a very careful inspection of the excavations then going on in Dock F, the most northern of the series : in this I was assisted by Mr. John Dickson, the contractors' engineer, who has had charge of all the excavations from the commencement. The sections are shown on p. 88. A-B (fig. 2) shows the face of the cutting of the south side of the dock, C-D (fig. 3) that on the north side ; they are seen in reverse directions. This dock over its whole area showed a much more decided and persistent arrangement of the beds than did any of the others. Commencing at the base, in section A-B, we have, in ascending order, No. 1, a bed of gravel and sand not bottomed, 5 feet ; No. 2, a bed of short hard clay containing many waterworn drift stones. This clay contains shell-fragments, and in excavating requires to be first loosened with the pick. No. 3, a bed of sand varying in thickness from 2 or 3 feet to a mere line. It is remarkably persistent all over the dock ; it appears to be a line of erosion running nearly in one plane with a slight dip towards the river, excepting in places where it curves into hummocks, as shown in section C-D (fig. 3), where it in one place develops into gravel, and at another is split up by a tongue of clay.

No. 4, strong plastic clay which has to be got with the grafting-spade, consequently costing more labour in the getting. It contains many erratic boulders, principally of diorite, the largest measuring 4 ft. 6 in. by 4 ft. 6 in. by 4 ft. 6 in. I counted thirteen lying at the S.E. corner of the dock. It is about 13 feet thick at the east end, but thins down to about 7 feet at the west end of the dock. Bricks are made from this clay for use in the dock-works. The clay No. 2 is unfitted for brickmaking.

No 5 is a Postglacial silt, in which many bones of Cetaceans have been found, also red deers' antlers, skulls and bones of a small variety of horse &c. They usually lie near the base, which rests on the Boulder-clay.

As these last sections were decidedly the most markedly stratified, it was of importance to find out if any distinctions occurred in the organic remains which they contained. This could not very well be done through evidence of the Mollusca, their remains, though present, being scattered and fragmentary, and no heaps of clay being left from which weathering would separate them, as happens in brick-fields. I therefore submitted, for microscopic examination

Figs. 2-5.—Sections exposed in excavating the Atlantic Docks, Liverpool. (Horizontal scale 240 feet to 1 inch, vertical scale  $\frac{1}{8}$  inch to 10 feet.)

Fig. 2.—Section on South side of Dock F (A-B on plan, fig. 1).

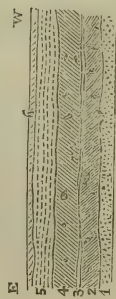
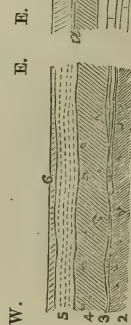


Fig. 3.—Section on North side of Dock F (C-D on plan).



1. Gravel, sand, and shingle.
5. Silt.

Fig. 4.—Section in Branch Dock No. 2 (E-F on plan).

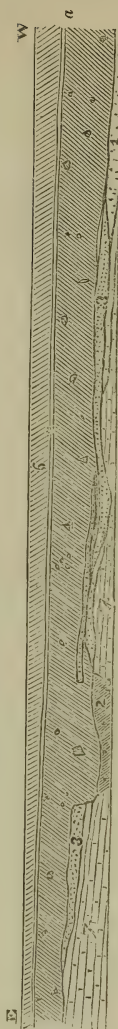


Fig. 5.—Section in Branch Dock No. 1 (G-H on plan).



2. Stony Boulder-clay.
6. Filled-up stuff.
3. Gravel, sand, and shingle.
7. Red Rock (Trias).
4. Boulder-clay, got with the spade.
- a. Old shore-line of present river.

specimens of the several beds, weighing about 8 lb. each, to my friend Mr. David Robertson, F.L.S., F.G.S., of Glasgow, who kindly made a very full Report, which I annex in an appendix.

It will be observed that bed No. 1 contains a few freshwater Ostracoda among numerous fragments of marine shells.

As I believe from other evidences that this is the nearest approach to a littoral deposit we find in our Drift, it might well happen, if a side stream had entered the Mersey at this point, that freshwater Ostracoda would get mixed with marine remains.

No. 2, the reddish-brown clay, consists of 60 parts of mud, 32 of sand, and 8 of gravel, about one half of the sand and gravel being more or less angular, the other half well rounded, and one piece finely striated.

No. 3, red muddy sand, much waterworn, contained very small chips of shells and a fragment of a starfish and one Foraminifer.

No. 4, red clay, consists of 58 parts fine mud, 20 of sand, and 22 of gravel, mostly small and waterworn.

It is unnecessary for me to give more particulars, as they will be found in Mr. Robertson's very careful report; but it is important to notice the effect of the differing proportions of the three constituents, viz. mud, sand, and gravel, on the nature of the clay. It will be observed that bed No. 4, which I describe as plastic clay from which bricks are made, contains 2 per cent. less sand than clay No. 2; but the sand is replaced by a larger proportion of gravel, which does not tend to make the clay "short" as sand does. The gravel is not very noticeable to the eye; but on attempting to cut the clay with a knife, its presence is very soon discovered; at the same time I was hardly prepared for so large a proportion of gravel as 22 per cent.

I have dwelt much on these sections, as it is seldom one has an opportunity of examining excavations on so large a scale, and they are instructive as showing how the beds of which the drift is composed vary as new faces are exposed.

I have given an exact and literal description of the appearance of the beds, leaving for discussion afterwards whether it is possible geologically to separate them.

*The New Garston Dock.*—These excavations I have already described in a communication to the Liverpool Geological Society\*, therefore it will suffice to say that the Boulder-clay here rests upon a very regular shelf of rock covered with the usual red sand and rubble, varying from a few inches to three feet thick. In some places current-bedded sand and gravel, and mixed clay and gravel, occur between the red sand and the Boulder-clay.

Garston is about 5 miles above Liverpool, on the same bank of the Mersey.

*Widnes.*—The deposits here are described in the paper on the "Buried valley of the Mersey" already alluded to†. The deepest

\* "The Glacial and Postglacial Deposits of Garston and the surrounding District, with remarks on the structure of the Boulder-clay," Proc. of the Liverpool Geol. Soc., Session 1874-75.

† Proc. of Geol. Soc. of Liverpool, Session 1872-73.



bering, No. 5, at Lambert's copper-works, showed the rock to be 163 ft. below the surface.

The bulk of the clay penetrated by the various bore-holes was of a very fine plastic nature, like that used by the New Ferry Brick and Tile Company. There did not appear to be many stones in the clay; but they were said to increase near the bottom both in number and size. There were erratic pebbles mixed with the red sand. A piece of cannell and some pieces of bituminous coal were found in one of the wells, 49 ft. from the surface.

*Sankey Bridges.*—The Boulder-clay was here penetrated to 100 feet below the surface, the last 20 feet showed 5 feet of sand mixed with coal-dust, and 15 feet of clay with bands of gravel. A sand-and-gravel seam 2 feet thick was passed through about 53 feet from the surface.

*Cheshire Lines, Liverpool Extension Railway.*—Between Garston and Warrington there were some excellent sections of the Drift disclosed from the beginning of 1872 until the middle of 1873. One continuous section commencing at Garston was  $3\frac{1}{10}$  miles long. The whole of the features hitherto described as distinguishing the drift were to be found in one place or the other in this section.

The diagram (fig. 6) exhibits, as accurately as I could depict it, the varying nature of the drift.

Speaking generally, the Boulder-clay was divided by very persistent seams of sand as at A, though in places these thinned out and the upper and lower beds coalesced and became one with no observable division as at B B, or the gradation from clay to sand was undefinable, as at C C. The sand beds were often distinctly stratified, as at A. The beds of sand were occasionally arched and laminated, as at E. On some of the sand beds the clay immediately resting upon them was in book-leaf laminations which showed very plainly by weathering, as at F; or the bed of sand actually terminated in laminations as at D. The usual red sand and rubble, G, occurred at the base of the clay when the rock H was reached.

At one point a gravel-bed occurred between the clay and the rock. In places the lower part of the clay was decidedly harder and stonier than that above, as at L; but this quality was not always persistent; it also contained beds of gravel, as at M. The upper part of the clay, as is common, was split by shrinkage, and broke, with blue faces or irregular joints to the sand-seams below. Irregular sporadic patches of sand occur in the clay, as at J. The usual glacial erratics and boulders were met with. In one place thin beds of clay, A'A', were interstratified with the sand; I saw no boulders in the sand-seams; but I cannot affirm that none were met with. Shell-fragments were to be picked up; but they were not very frequent; they are given in my list, Part I.

Hitherto I have made no remarks on the shell-fragments; but they are to be found more or less in all the clays I have described, occasionally in the sand-seams. Some sand appears utterly barren; but the clay always contains them.

The section at Farnworth (fig. 7) was just over a mile long; and

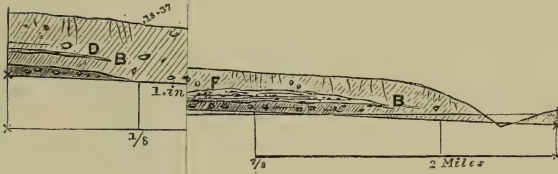
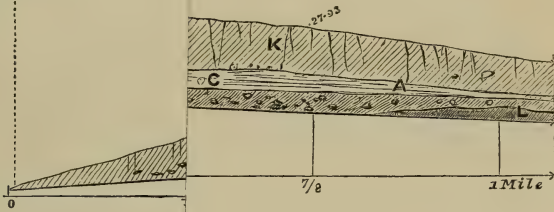


[To face p. 90.]

Fig. 6. *ond Garston Station.*

Road Halwood  
to Speke.

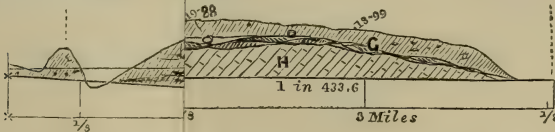
om  
Speke.



L. & N. W. Railway,  
near Allerton Station.

s Road,  
Liverpool.

Junction with line to  
Brunswick Station.











here for  $\frac{3}{4}$  of a mile the Boulder-clay was split in two by a persistent seam of sand, N, not more than 6 inches thick; the surface of the clay and the imbedded seam of sand followed pretty closely the contour of the rock, O, below. The remainder of the cutting showed a seam of sand, P, also; but it was not so defined, and appeared to thin out to nothing at either end or lose itself in indefinable divisions or ramifications, P'.

Shell-fragments were in the sand-seam. The base of the clay rested on the usual red sand, Q, degraded from the rock below. Nearer Warrington there was a cutting in the Boulder-clay; but it presented no features to individualize it.

*Wigan Junction Railway.*—These sections are described in my paper "On a Section through Glazebrook Moss" (Quart. Journ. Geol. Soc. vol. xxxiv. pp. 808–810). The same feature of a divisional seam of sand shows in the cutting; but a bed of "book-leaf" clay 18 inches thick, 8 feet from the surface and a quarter of a mile long, distinguishes the section.

*Cheshire Lines* from Hunt's Cross to Aintree.—I examined the sections along this railway while it was being made in 1876–7. The same peculiarities occur at the base of the clay where it is seen resting on the rock, viz. red sand and occasional gravel-beds. There were a few seams of sand in the clay itself; but there was nothing peculiar to mark these sections from the last.

*About Liverpool.*—Excavations in the City of Liverpool show the Boulder-clay resting on the red sand; and I have seen very large erratics taken out of them. It

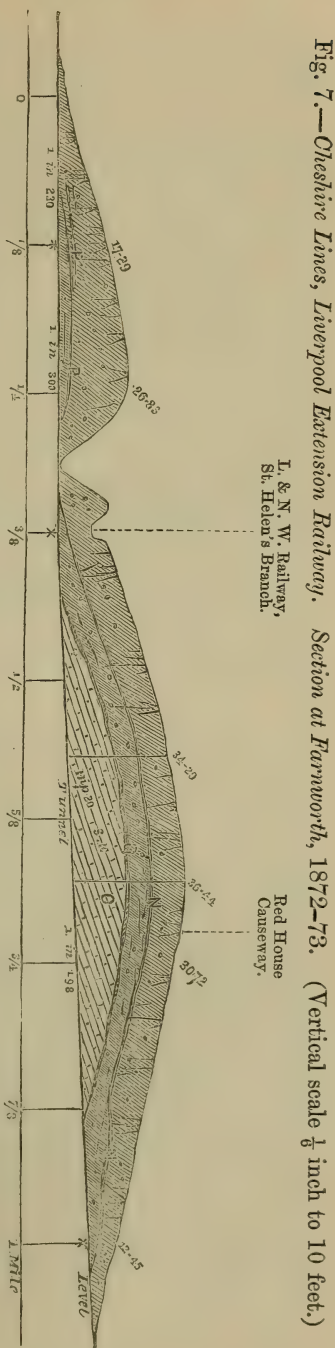


Fig. 7.—*Cheshire Lines, Liverpool Extension Railway. Section at Farnworth, 1872–73.* (Vertical scale  $\frac{1}{8}$  inch to 10 feet.)

is very striking to see these records of a Glacial age extracted from under the busy offices and warehouses of Liverpool. Brick-pits are studded all round the town. In the excavations of the Granby-Street Board Schools, Toxteth Park, of which I was the architect, the Boulder-clay was covered, first with a soft blue clay, evidently the washings of the Boulder-clay, probably subaerial, about 2 feet thick, then "Washed drift sand," covered by a peat-bed with remains of firs therein, and then surface soil. There is nothing special to notice about the clay of the brick-pits. When the Boulder-clay is absent, granitic and other glaciated erratics are often met with resting directly on the rock. In an excavation on the side of the lake in Sefton Park the surface of the rock below thin beds of sand and gravel was worn smooth as if by a stream of water. A section of the cutting at Bootle-Lane Station is given in Part I. of this paper, Feb. 1874, p. 28; the bed of Boulder-clay No. 6 resembles the bulk of the clay disclosed by the Widnes boreholes.

*River-cliffs*.—One description will do for these Boulder-clay cliffs.

At Egremont there is a divisional seam of sand in the Boulder-clay; and Mr. Mackintosh\* argues that below this the clay is "Lower Boulder-clay," and above it the "Upper." Between the Dingle and Garston a similar divisional seam of gravel occurs. I will reserve the discussion of the relations of these beds until my description is finished. The cliff south of Garston also shows a divisional plane with a few pebbles marking it. Boulder-clay cliffs are to be seen near Eastham; but to describe them would be only reiterating what I have already said.

#### *Drift on the Cheshire side of the Mersey Basin.*

That portion of the peninsula of Wirral draining into the Mersey is generally, excepting over the more prominent elevations, covered with a Boulder-clay answering to that on the Lancashire side; where the base is exposed the same phenomenon of red sand and rubble and yellow sand and rubble, according to the nature of the underlying rock, is to be seen. This I observed at the excavations for the new Birkenhead Station, in excavations for houses at Oxton, and in sand-pits in the Happy Valley, Tranmere†. Striated rock-surfaces have been recorded also from time to time by various observers. From an examination I made in 1877, before reporting to the Wallasey Board on a site for the proposed cemetery, I came to the conclusion that on the coast just beyond the "Red Noses" there exists a sea-cliff buried in Boulder-clay, which is again covered with blown sand. Borings at Leasowe Castle by Mr. Cunningham, reported to the British Association in 1854, also showed that there was a considerable and undetermined thickness of Boulder-clay near the shore. The phenomenon of deep rock-gullies filled in with drift also

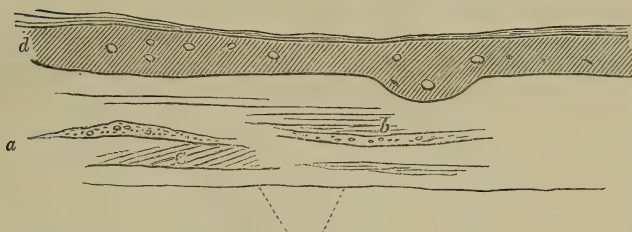
\* Quart. Journ. Geol. Soc. vol. xxxiii. 1877, p. 732.

† Described by Dr. Ricketts in Proceedings of Liverpool Geol. Soc., Session 1876-77, p. 254.

occurs at Tranmere Pool and at Hooton, thus bearing out the inferences drawn from the Lancashire side\*.

At Upton, in May 1873, I examined with Mr. Shone a sandhole which showed a section of current-bedded sand and gravel with rolled pebbles of Red Sandstone mixed with erratic pebbles (fig. 8); in it the usual shell-fragments occurred. The whole was overlain by a thin bed of Boulder-clay of irregular thickness, containing only a small proportion of stones. I have very seldom found rolled pebbles of Triassic rocks, except in some of the clay of the dock-excavations on the Lancashire side; and this is worth bearing in mind. The same section, excepting that the sand is of a flesh- or reddish colour generally, was to be seen at the Backford sandhole. Here the valley is about 50 feet deep, and must formerly have been filled with sand, which has been denuded.

Fig. 8.—Section in Sandpit, Upton.



- a. Sands and gravels.
- b. Bed of gravel containing many rounded pebbles of red sandstone.
- c. Current-bedded sands containing beds of gravel, in which are many fragments of shells, especially in the gravel.
- d. Boulder-clay with few stones.

*Helsby and Frodsham.*—Ascending the Mersey, the Boulder-clay skirts the foot of the Helsby and Frodsham hills which overlook the upper marshes of the Mersey. When, however, we follow the valleys which ramify among these hills, we find they are largely filled with a sandy drift not unlike that at Backford. A section disclosed by a well I sunk at the late Mr. George Eastee's house, about a mile from Helsby, showed 20 feet of yellow flesh-coloured and red sand, evidently arranged by water, with a seam of clay about the middle of it, the whole resting on soft rock.

On the northern face of Helsby Hill, about halfway up, a cutting at the side of a road showed the following section (fig. 9), the relation of the Drift to the escarpment of Helsby Hill being shown in fig. 10.

*Valley of the Weaver.*—From Frodsham up to the Grand Junction Viaduct the river Weaver runs through a deep valley cut in the

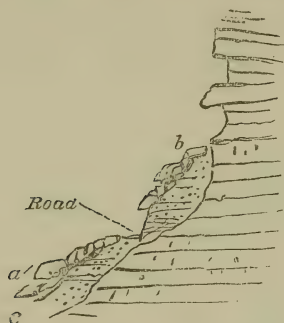
\* "Buried valley of the Mersey," Proc. of Geol. Soc. of Liverpool, Session 1872-73.

Fig. 9.—Section on side of road, northern face of Helsby Hill.



1. Hard flesh-coloured Keuper sandstone.
2. Fine yellow laminated sand with interlaminae of reddish clayey sand, very regular and distinct, with a slight slope up the hill; occasional waterworn travelled pebbles occur, principally near the top.
3. Sand blackened with iron oxide ("fox-bed").
4. Subaerial detritus, or "talus," from the cliffs above, with white sand filling the interstices between the rubble, and large irregular blocks which were freely strewn on the slope. I could find no shells. At several points along this road are to be seen very large granite boulders lying in the sand-drift.

Fig. 10.—Section showing the position of the Stratified Drift in relation to the escarpment of Helsby Hills.



*a, b.* Talus of angular blocks of Red Sandstone, lying upon and covering stratified yellow sand (*c*) containing occasional rounded drift-pebbles.

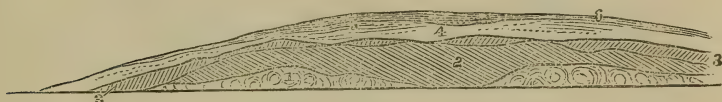
Keuper marls. At one point there is a remarkable basin-shaped sweep from the cliffs on the right bank of the river, looking very like the effect of a large landslip afterwards modified by rain. There is a remarkable absence of drift in this valley, which is worth noting. On the plateau on each side drift can be found. About Aston there is generally sand covered with sandy clay and then with yellow sand; and near Aston Grange the Boulder-clay is to be seen in the farmyard. Erratic boulders are also to be met with.

*Stockport.*—In April 1874 I examined and drew a section (fig. 11) of the drift disclosed in the London and North-Western Railway Company's ballast-pit at Stockport. At the base was very light yellow sand, 1, in all sorts of curved contortions, looking at a distance like



rock. Resting upon an uneven surface of this bed was a bed of current-bedded sand and gravel, 2. Above this occurred lenticular patches of clay, 3, almost forming a continuous bed, and of irregular thickness. The whole was capped by stratified sands and gravels, 4 and 5, and surface soil, 6. The river Mersey runs in a valley much below the level of this drift; and no doubt there has been considerable river-denudation.

Fig. 11.—Section in Ballast-pit, Stockport.



- |  |            |          |
|--|------------|----------|
| 1. Light yellow sand, contorted.           |            |          |
| 2. Obliquely stratified sands and gravels. |            | 3. Clay. |
| 4. Stratified sand.                        | 5. Gravel. | 6. Soil. |

*Hazel Grove.*—A somewhat similar series of sand and gravel beds on a small scale occurs at Hazel Grove; and there are many Triassic and Carboniferous pebbles in it.

*Poynton.*—Boulder-clay is to be seen in a brick-pit at Poynton. The erratic stones are distinguished by being very much weathered. The nature of the clay is evidently affected by the neighbourhood of the hills of Carboniferous sandstones and shales, being of an arenaceous nature and of a yellowish hue. It appears to rest upon a sand like that of the Macclesfield-Cemetery beds.

*Macclesfield.*—About the same date I also examined the Macclesfield-Cemetery beds described by Mr. R. D. Darbishire, F.G.S., in 1865\*. The section exhibited a considerable thickness of current-bedded yellow sands and gravels with shell-fragments. Mr. Darbishire estimates these beds at 70 feet thick, and states that they rest on Boulder-clay. He enumerates 49 species of marine shells from them. The elevation above the sea is stated at from 500 to 600 feet.

Beyond the bridge over the Macclesfield canal, at about 550 feet above ordnance datum, was a brick-yard consisting of purple-red clay covered with yellowish arenaceous clay. The contained stones were more rounded and weathered than those about Liverpool. I found several flints, one being about  $2\frac{1}{2}$  inches in diameter.

In a stream by the "Setter Dog" was to be seen the drift-gravel first described by Mr. Prestwich. The gravel is very peculiar, being full of loamy matter; and along with well-worn travelled gravel are angular, subangular, and flat flaggy pieces of Carboniferous sandstone. It is very singular to find this isolated patch of marine gravel full of shell-fragments among these hills. The neighbouring hills have only a thin covering of subaerial detritus; but erratics of Buttermere syenite and greenstone are to be found scattered over them as far as the "Bow Stones." I saw no evidences of

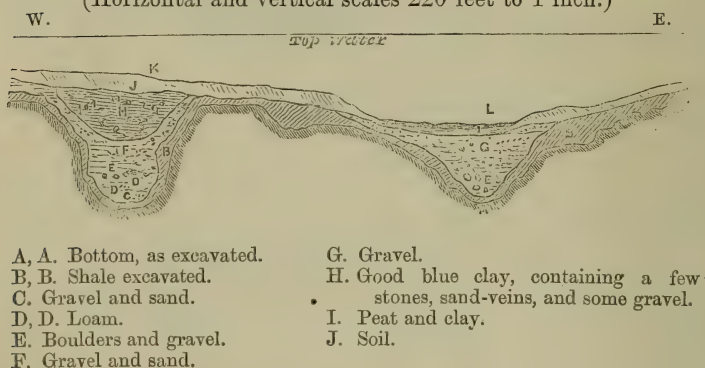
\* Memoirs of the Literary and Philosophical Society of Manchester, vol. iii. series ii. pp. 56-66.

striation or planing on any of the numerous erratics I examined. There is at Styperson, covering the rock, a red clay with erratic stones; but all over these hills, as far as Whaleybridge, drift is generally absent.

*Drift of the Rivington Hills.*

Perhaps the most interesting section of the Drift occurring among the hills was that shown by the excavation for the puddle-

Fig. 12.—*Turner's Trench, Yarrow Reservoir, 1872-75.*  
(Horizontal and vertical scales 220 feet to 1 inch.)



wall of the Yarrow Reservoir at Rivington\*. The site of the reservoir is to a large extent in the coal-shales, as proved by the tunnels and trenches. The river Yarrow runs from Allan's Bridge into the Anglezark Reservoir; and the valley dammed up by the embankments thrown across at two points to form the Yarrow Reservoir is a side valley, which the excavations proved was the Preglacial valley of the Yarrow. This had been sufficiently filled up with drift-deposits to divert the river up to the valley of the Anglezark Reservoir. The excavations for what was called Turner's Trench (fig. 12) disclosed a gully in the solid rock 140 feet deep from the surface, which, from the winding of its course, was intersected by the same trench in two places, G and H. The bottom was in Millstone Grit, which had a surface highly waterworn. The lower part of the gully, Mr. Martin, the resident engineer, informed me, was filled up with gravel, sand, and large stones, the largest being boulders of Millstone Grit. The upper part was of blue Boulder-clay; and throughout there were waterworn boulders and pebbles of limestone, granite, porphyry, and greenstone. The excavation for the puddle-wall of the Yarrow embankment intersected the same gully at a higher level, and was filled up with loam, sand, veins of gravel, and boulders (fig. 13).

\* The Yarrow is a tributary of the river Douglas between the Mersey and the Ribble. Not having devoted a special division to the basin of the Douglas, the description of the Drift is most naturally in place here.

The sections of the two trenches are from diagrams and descriptions kindly given me by Mr. Martin, the resident engineer.

Fig. 13.—Section in Yarrow Trench, Yarrow Reservoir, 1872–75.  
(Horizontal and vertical scales 220 feet to 1 inch.)

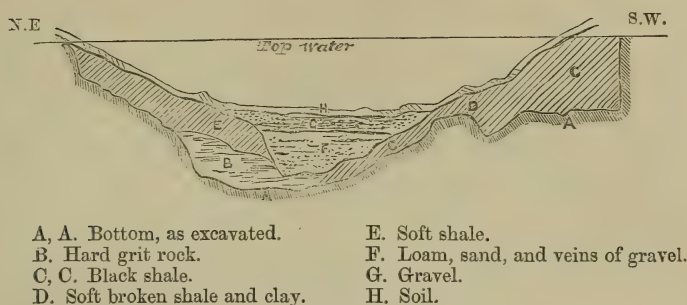
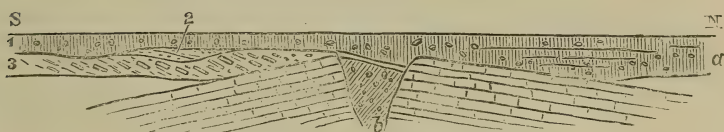
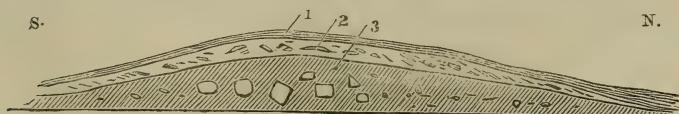


Fig. 14.—Section of Turner's Side Trench, Rivington.  
(Scale as in fig. 12).



1. Brown clay with boulders.
  2. Sand and gravel current-bedded, together and mixed with clay.
  3. Rubble debris of coal-shale in large angular blocks.
  4. Coal shales.
- At *a* the clay was not bottomed at 20 feet deep.  
*b* is supposed to be another section of the gully.

Fig. 15.—Section in Cutting on the west side of Yarrow Reservoir.



1. Yellowish clay, 3 feet.
2. Brown clay with angular fragments of coal shale.
3. Blue clay (Till) very hard, but falls when wet—full of pebbles, and containing many Millstone-grit boulders (up to 8 tons) mostly waterworn, but none glaciated.

I examined these excavations in May 1872, and again in January 1875. Turner's Side Trench, a bend in Turner's Trench along the side of the hill, showed a section of coal-shales, with an angular rubble débris resting on the upturned edges of the shale (fig. 14). Upon this lay a patch of sand and gravel, current-bedded, the whole being overlain by brown clay with boulders. At another point in the reservoir the side of the hill was being excavated for clay for the puddle walls, and for material to form the embankments (see fig. 15).

The working face was 200 feet long and 16 feet deep. The lower stratum was of Boulder-clay, blue-grey in colour, un laminated, and very hard, but falling with water. The clay was very full of pebbles and Millstone-grit boulders up to 8 tons in weight, which had to be blasted. I have since seen the Scotch Till, and find this Yarrow Boulder-clay to be a deposit apparently identical with that found on the Carboniferous areas of the Clyde and Forth\*.

Upon this "Till" lay a brown clay containing angular fragments of Coal-measure shales; and the whole was capped by a yellowish clay about 3 feet thick. There were no signs of shells or shell-fragments about; nor had any been found. The deposit was evidently unfossiliferous. In 1875 I saw a similar excavation, also on the west side of the valley, in the Till, which was of a grey colour and full of limestone, granite, syenite, and greenstone boulders, all rounded and slightly scratched indefinitely over the whole surface. The limestone showed the scratches plainly. The deposit was hard and compact, requiring a pick to disturb it; and, as I noted at the time, it answered to the description of the Scotch Till, which I have since verified by examination.

The level of the reservoir is about the 500 feet contour. At Adlington, at a lower level, I found a clay used for making bricks similar to our marine Boulder-clay, but containing more pieces of shale, and in it one small fragment of a bivalve.

So far I have confined my description entirely to personal observations. Over so large an area as the Mersey-basin, containing some 1748 square miles, there are necessarily numerous places left entirely undescribed. Still I think sufficient has been given to form a fair general view of the distribution of the Drift in it. It would be only wearisome iteration to go on further describing section after section.

Before proceeding to describe the deposits in other river-basins, it will be well, while the facts are in our minds, to try if we can discover any general principle which will connect all these detached observations.

#### *Observations on the preceding Sections.*

A glance at the large map I have prepared (Pl. V.), showing the position of the preceding drift-sections in relation to the geological formations and drainage-lines of the country, shows at once that there is an intimate connexion between them and the nature and distribution of the Drift. The greatest depth of Boulder-clay is at

\* "The Glacial-beds of the Clyde and Forth," Liverpool Geol. Soc., Session 1879-80, pp. 139-153.



Widnes, near the mouth of the river Weaver, which, with its tributaries, is almost confined to the Keuper marls.

The extremely fine unctuous nature of the clay down to a depth of 140 feet from the surface, together with the position of the deposit, points most conclusively to the river Weaver as the origin of it. None the less clear to my mind is it that the whole of the Boulder-clay, as seen in the cliffs on either side of the river Mersey, from Runcorn to its mouth, and the fine clay in the North Docks, have a similar origin.

The plateau of Keuper marls also appears to have provided the matrix of the Boulder-clay along the valley of the Mersey up to Manchester. When we get to Stockport we are in the region of sands and gravels, as is also the case at Hazel Grove. Here the drainage is from the steep hills of Carboniferous sandstone; therefore it is a natural and fair inference that the character of the Drift has changed from this cause.

At Macclesfield we again come onto the Boulder-clay and overlying sands and gravels; and as that town is situated at the foot of steep hills of Carboniferous sandstones on the one hand, and the Keuper-marl plateau on the other, we are led to conclude that the sands have come from the one, the clays from the other. The northern side of the Mersey is occupied with Triassic rocks; and beyond lie the Coal-measures.

May not these have supplied the material for the included beds of sand found in the Boulder-clay? At Upton, in Cheshire, the drift again changes; but here we are getting very close to the drainage of the river Dee, which is largely fed from a sandstone area; so now I will proceed to examine the drift found in the basin of the river Dee.

#### DRIFT OF THE BASIN OF THE RIVER DEE.

From West Kirby to Parkgate, on the east bank of the estuary of the Dee, is a cliff of Boulder-clay which has attracted some attention. The section at Dawpool has been described by Mr. Mackintosh in the *Quarterly Journal of the Geological Society*, vol. xxviii. pp. 388-392, and vol. xxxiii. pp. 731, 732. Nearer to Hoylake the cliff is lower, and overlain by blown sand. Between the blown sand and the Boulder-clay is a bed of Postglacial blue silt or clay, 1 foot 9 inches thick and 4 feet 6 inches above high-water level; further up the estuary this bed rises to 9 feet above the same level, with a thin bed of soil under it, and then sand lying on the Boulder-clay.

The highest level of these Postglacial beds noticed by me is from 12 to 14 feet above high-water. They consist of blue clay containing a few pebbles underlain by yellow sand resting upon the Boulder-clay. The Boulder-clay is of a deep purple colour. As you approach Dawpool the cliff becomes loftier, and has in it a thin bed of intercalated sand and gravel. Further on, again, the cliff was of homogeneous Boulder-clay.

I have examined these cliffs at various times; but the sections  
Q. J. G. S. No. 154.

differ more or less from time to time. In December 1872 I made sections at several points (figs. 16-19). There are in the Boulder-clay sand and gravel seams more or less persistent, sometimes two, occasionally a third, and sometimes only one, or, it may be, a seam of finely laminated clay, the clay above the sand seams or seam having blue facings. The lower part of the clay below these seams is largely mixed with red sand, and appears to contain a much larger percentage of rolled boulders or pebbles than the upper.

The base of the Boulder-clay in other localities is often distinguished by these two features (see section at Bootle-Lane station, Part I., Quart. Journ. Geol. Soc. vol. xxx. p. 28).

The base of the Boulder-clay is nowhere to be seen on the east margin of the Dee.

There are a great many very large erratics on the shore near Dawpool; these have been already pretty fully described by Mr. Mackintosh.

In May 1873 I examined with Mr. Shone the excavations of the West Cheshire Lines Railway near to Chester. This section showed a large development of sand, to some extent stratified, capped mostly, but not invariably, with a bed of fine purple Boulder-clay containing but few stones. In some places the junction between the sand and the clay formed a very irregular line. A section of this cutting is given in Mr. Shone's paper, Quart. Journ. Geol. Soc. vol. xxxiv. p. 384. The sand occasionally contained thin beds of clayey sand; at one point the junction of the sand and clay was nearly vertical. The sand, to all appearance, contained neither boulders nor gravel.

*River Alyn.*—This river is a tributary of the Dee. In the right bank towards Rossett, forming a spit of land between the valley of

N.

Fig. 16.

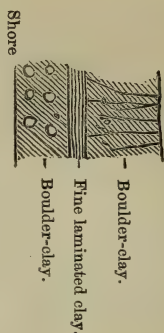


Fig. 17.

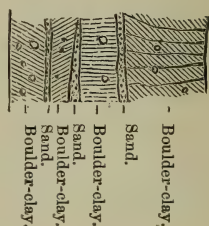


Fig. 18.

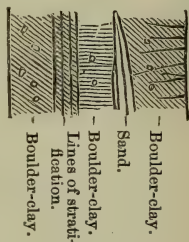
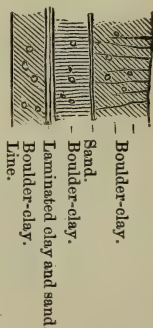


Fig. 19.

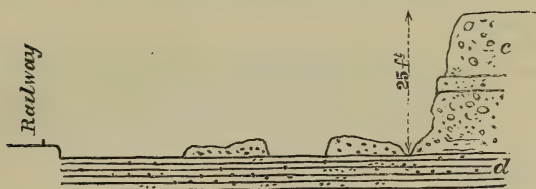


Figs. 16-19.—Sections of Cliffs at various Points between Parkgate and West Kirby.

S.

the Dee and Alyn, is a very high bank of shingle. None of the stones were scratched. They consist of Silurian grits, Mountain Limestone, felspathic and trappean rocks, greenstone, small pebbles of granite, cherty limestone, syenite and Millstone Grit. On the opposite bank and higher up the river, a landslip (August 1873) displayed stratified sand with thin bands of gravel and, in some places, fragments of coal. At one point there appeared to be seams of peat; but an examination showed they were composed of rounded pieces of coal-shale closely packed together. I picked up fragments of *Cardium* and *Tellina*; but they were not plentiful. On the east side of the railway between Wrexham and Gresford is a ballast-pit (fig. 20) showing gravel, shingle, and boulders (c) lying upon stratified sand (d).

Fig. 20.—Section in Ballast-pit on the east side of the Valley between Gresford and Wrexham.



- c. Gravel and shingle mixed with sand.  
d. Stratified sand.

The bed of shingle and gravel was mixed with sand, and was about 25 feet high. There were some large granite boulders among it mixed with stones common to the Lancashire drift and with local stones and coal-shales.

The local stones greatly preponderated.

At Chirk we come upon the Dee again, and from the railway viaduct can be seen a very great depth of half-rounded shingle which has been cut into by the river on its right bank.

Higher up the river than Llangollen and about Corwen are great hills of gravel and sand drift showing curved bedding; these beds are cut into cliffs on either side of the valley. Near Carrog station the drift is very full of boulders. At Cynwyd station there is a deep cutting in a buff-coloured clayey drift containing boulders. Near Llandillo there is a good section of bedded sand and gravel.

At Bala station there is a drift of angular, subangular, and slaty shingle. Between Bala and Dolgelly, massive rounded boulders are seen resting upon the rock. Here are also gravel mounds. There are immense boulders in the gravel. The shores of Bala Lake by the railway show gravel, shingle, and large boulders in the shallows of the lake.

#### *General Observations on the Drifts of the Dee Basin.*

The Boulder-clay of the estuary of the Dee is generally similar to that of the Mersey.

The same vertical arrangement, generally speaking, prevails; that is, the base of the sections often consists of a clay evidently considerably mixed up with the grindings of the Triassic rocks beneath. Rounded boulders are also more plentiful in the lower beds. I have seen, however, no shingle or gravel beds at the base such as I have described as occurring at the Atlantic Docks, Liverpool; but then there have been no excavations made that could disclose them, and the actual base of the clay is seldom visible on the Dee estuary.

Fibrous gypsum from the Keuper marl is often met with in the Cheshire Boulder-clay. I have in my possession a large piece taken out of the dock-excavations, Liverpool; but it is not so plentiful in Lancashire as in Cheshire. The contained stones in the estuaries of the Mersey and Dee are practically the same in character. The greater depths of Boulder-clay usually lie in the valleys. At Ford a boring showed 83 feet to the rock. It is probable that there exists a considerable thickness of Boulder-clay to the seaward of the peninsula of Wirral.

Towards Chester, as shown in the section of Upton sand-hole (fig. 8) and the section of the West Cheshire Lines described at page 100, sand comes in in much greater force as a constituent of the drift sections; and as we proceed up the Dee and branch off into the river Alyn we find very great deposits of stratified sand and banks of shingle.

It would thus appear that the drifts of the Dee basin as well as those of the Mersey are intimately connected with the nature of the strata through which the river runs, and the respective levels of its course. Very little of the Dee is fed from the Keuper marls, which accounts for the preponderance of sands and gravels in its basin—excepting in the lower parts of the estuary, which could be fed as readily from the Keuper Marls of the Mersey basin as the Mersey itself, as I propose to show in my concluding remarks.

#### DRIFT OF THE BASIN OF THE RIBBLE.

My observations of the drift of this basin are limited; but as Mr. C. E. De Rance gives a very full account of them in his "Superficial Geology of the Country adjoining the Coasts of South-west Lancashire" (Memoirs of the Geol. Survey), this is of the less importance, and my aim is, as far as possible, not to repeat what others have described.

The following are from my notes:—

A section disclosed by a side gully of the Ribble running up to Pinfold by Fiswick Hall showed stratified sand with beds of very fine gravelly sand containing very rotten shell-fragments. A bed of Boulder-clay lay against this bank, having a junction almost vertical; but it may have occurred from a land-slip letting down an overlying clay.

At Bezza Brook we see the red shaly rock at the base and many boulders and erratics in the bed of the brook. A section of the drift, about 8 feet deep, is disclosed, consisting of, first, mixed blue clay and gravel lying on the shale, then Boulder-clay with gravel, and

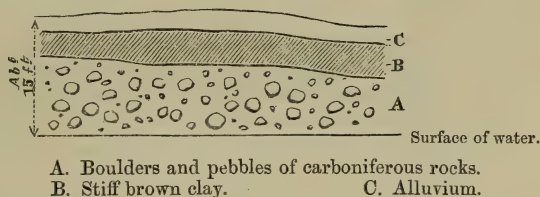


subaerial clay and soil capping the whole. Below the foot-bridge a section in the same brook shows Boulder-clay overlain by a foxy-brown sand. Higher up the Ribble than Bezza Brook, and on its left bank, where the river with a great sweep cuts into its bank, is a very steep section of sandy drift and clay, loose and denuded by the river sweeping its base. The sand is seen to rest on the Triassic rock just above the level of the river.

At Ribchester, on the right bank of the Ribble, some instructive sections are seen; and here we find a lower bed of a different character come in, gradually developing up to Mitton Bridge, where it may be observed in greater force.

This lower bed, A (fig. 21), consists of rounded boulders and pebbles of Carboniferous sandstones and limestones overlain by a stiff brown clay, B; C is alluvium. Not far from this section, on the same side

Fig. 21.—Section in the left bank of the Ribble, near Ribchester.



of the river, this boulder-drift lies upon a blue Till, containing coal-shales.

This Till has in it oblique bands of a brown clay; above it is a laminated clay, an alluvial clay capping the whole.

On the opposite side, or left bank, we see a reddish-coloured sand resting upon the irregular surface of the blue Till; and at another part of the same cliff the blue Till is seen to rest upon curved and distorted shales.

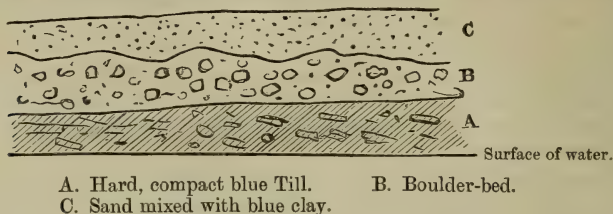
Below Whalley, on the left bank of the Calder, before it joins the Ribble, a cliff about 10 feet high shows a bed of sand and gravel with Carboniferous-grit boulders, and a few Carboniferous-limestone boulders and some of a very fine hard grit. Following the Calder, on the right bank above Whalley, on the road to Padiham, there is a sand-pit showing a face of sand 15 feet high, unbottomed. The sand drift contains few stones; but bits of coal are distributed through it. Further on slips in the road (which follows the valley-side) show that drift of this nature continues for some distance.

Near to Padiham, by Huntroyde Brook, a quarry by the road-side showed reddish-brown clay with a few pebbles (the general top-clay of the district), lying upon the Carboniferous sandstone rocks.

Returning down the Calder, at Cock Bridge (left bank), is a very interesting section. Here the rounded-boulder bed B (fig. 22), consisting almost entirely of Carboniferous sandstones, is capped with sand mixed with blue argillaceous matter, C, and it rests upon a very hard

compact blue Till, A, full of scratched Carboniferous-limestone boulders and pebbles.

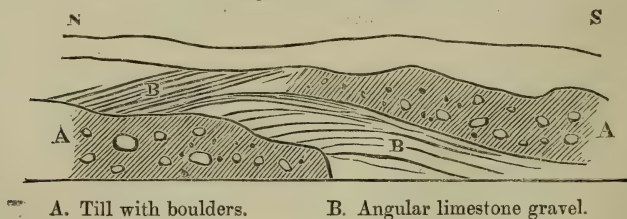
Fig. 22.—Section in the left bank of the Calder, near Cock Bridge.



The limestone boulders are irregularly scratched; and the stones are partially rounded. It precisely resembles a Till very commonly met with in the west of Ireland, in Galway and Clew Bays. This bed is remarkable as containing stones not found in the basin of the Calder; and it appears to have been forced up through a comparatively narrow gorge from the Ribble basin\*. At Mitton Bridge, on both banks of the Ribble a rounded-boulder drift (principally limestone) is seen resting upon a blue limestone Till similar to that just described as occurring on the Calder. The whole are seen to rest on Carboniferous shales.

Ascending the valley of the Ribble, we find the Drift changes to a more moraine-like character. At Ribble Bank a gravel-pit on the right of the road from Settle to Moughton contains boulders of both dark- and light-coloured Mountain Limestone, often fossiliferous, intermixed with hard grit and some sandstones in a matrix of Macadam-like gravel. At the Craven Lime Company's quarries, nearer Moughton, some very interesting sections were disclosed, which I give. Fig. 23 shows moraine-like, hard, calcareous Till standing

Fig. 23.—Section in the Craven Lime Company's Quarries between Moughton and Settle.



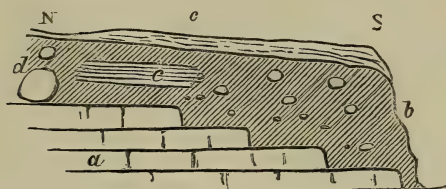
with a vertical face. The boulders in A, are mostly of light-

\* Since writing this, I find Mr. Tiddeman points out that there is in the gorge of the Calder a "roche moutonnée" well scratched, and also considers that the course of the ice was up the river and southwards (Q. J. G. S. 1872, p. 479).

coloured limestone (Scar limestone ?); the small ones are angular, the larger partially rounded. Laminated beds, B B, are of angular limestone gravel; it is just like the *worn* Macadam off a road. It contains a larger proportion of dark limestone than the Till it is imbedded in. This limestone is fossiliferous, whereas that in the Till hardly contains any fossils\*.

In fig. 24, *a* shows white Scar limestone partially worn on the surface but not glaciated, and in steps, as shown; *b*, Till similar to A in section fig. 23; *c*, laminated loamy bed; *d*, Silurian-grit boulder. These boulders of Silurian rock seem to be always at or near the bottom of the Till. A very large boulder of this rock was lying loose on the limestone.

Fig. 24.—*Another Section in the Quarries between Moughton and Settle.*



At the Ribblesdale Lime and Quarry Company's quarries at Moughton, just in front of the limestone Scar, the underlying Silurian slates are well rounded by glacial action over a space 200 yards by 50 yards; and probably much more rock similarly affected would be seen if the drift were cleared away. I traced this glaciated surface to within 20 yards of the limestone Scar; and it may approach it nearer, as the Silurians are covered with drift and quarry débris. This is extremely interesting as showing that the Scar has not receded more than 20 yards since a glacier filled Ribblesdale.

Descending again to the lower lands nearer the sea, we find in walking from the bluff on the Ribble above Bezza Brook, but below Ribchester, towards Blackburn that the drift gets yellow and full of local materials from the Carboniferous sandstones. At the base the débris seems to be from the coal-shales. The valleys have very steep sloping sides; and no flats or terraces occur after leaving the Ribble.

At Preston, Mr. De Rance says, the "Middle Sands" occupy a very large area of the town, one of these knolls rising to the surface, surrounded by the "Upper Boulder-clay to the north-west and east;" and he enumerates many of the public buildings that are built on this drift.

\* At the south end of this section a second "bench" showed that the Till was 12 feet deeper than in the section before the limestone rock was reached.

The surface of the sands he describes as "extremely undulating, often causing the Upper Boulder-clay to come in somewhat unexpectedly," p. 17. The long winding bluff forming the north margin of the Ribble valley, between Preston and Redscar, exhibits very fine sections of the "Middle Sands." Mr. De Rance describes many other sections; but they all consist in this valley of Middle Drift and Upper Boulder-clay, the former being in the greatest force; and he states that the four largest towns of the district are built on Middle Drift, viz. Preston, Kirkham, Chorley, and Leyland.

### *Remarks.*

The sections described in this basin are extremely instructive. If we begin and retrace the drift down the Ribble valley from Moughton in Ribblesdale, we find it first composed almost entirely of local materials, the limestone vastly predominating and providing not only the boulders but most of the materials for the matrix; as we descend this drift gets more and more mixed with Carboniferous sandstones and grits from the Pendle Hills and the tributary Calder, especially in the upper beds. The underlying blue Till still contains a preponderance of limestone rocks; but by far the most remarkable fact is that this Till has been forced up the gorge of the Calder against its drainage, as already described. As we near Ribchester the true low-level marine clays come in, overlapping the more local drift of the Ribble valley. Below Ribchester the drift becomes all marine, the yellow shelly sands being highly developed. The Triassic and Carboniferous sandstones have yielded the materials for these sands; and the red shelly Boulder-clay has been laid down upon it, apparently from a sea-drift. It is also a noticeable fact that the included granitic boulders and the true sea-drift stones from the Lake district so plentifully found in all Low-level Boulder-clays and sands almost, if not entirely, cease above Mitton Bridge.

### DRIFT OF THE COAST FROM BLACKPOOL TO ST. BEES.

At Blackpool there is a well-known section of Drift exposed in the sea-cliff. It was described by the late Mr. Binney, F.R.S., in 1852, in the Memoirs of the Literary and Philosophical Society of Manchester, and since by many other geologists.

Mr. De Rance especially has paid much attention to it. In August 1872 I made a very careful section of it from Bispham to Gynn, a distance of about 3600 yards, or just over 2 miles (fig. 25).

Commencing at the furthest point from Blackpool, viz. Bispham, and working south, the beds run in the following order:—First, there is a red Boulder-clay, A, not very stony, which a little further on has intercalated in it towards the top two thin bands of stratified sand, B; these curving downwards join two remarkably



persistent and regular bands of sand, C, lying upon and concentric with an arch of Boulder-clay, D; curving upwards further to the south, the two lower bands pass concentrically over another, larger arch of Boulder-clay, E, which becomes very stony. Eventually, after running a distance of over three quarters of a mile, the bands die out at F, as the arch dies into the shore. From the point where the intercalated beds of sand unite with the two bands lying on the Boulder-clay arch, the sands and gravels G set in, and increase in thickness; as we go south they pass over another length of this lower clay, H, which disappears towards Gynn, leaving only the sands and gravels some 28 feet thick. The upper part of the cliff consists of a continuous sheet of Boulder-clay, I, of a character less stony than that at the base. The greatest height of the cliff is about 60 feet.

It is interesting to compare this section, which I can certify as accurate for the time, with that given by the late Mr. Binney, F.R.S., 20 years earlier \*. Mr. Binney states that the cliff wastes away on the average one yard every year. If this be correct, the section I have given may be taken as 20 yards further into the cliff than Binney's, and approximately parallel to it: yet it is very different; for at Gynn, in his section, the sands and gravels have died into the shore, and the cliff is entirely of Boulder-clay, whereas when I saw it there were about 30 feet of sands and gravels. Neither have the sands and gravels a general dip southwards such as Binney shows.

If, then, the sands and gravels vary so much in such a short distance, can we assume that they are conterminous with the sands and gravels of the Ribble above Preston, 15 miles off in a direct line, and situated in a drainage-basin of 720 square miles?

For the time it was written, I consider Mr. Binney's description a very excellent one, though I think he would hardly, if he were now living, maintain that earth-movements had produced the arches of silt then to be seen.

The lower clay, E, underlying the sands and gravels is harder than that above, standing in places vertically. It contains more stones; and these are stated to be (though I did not verify it) mostly scratched. Comparing the proportion of the various rocks composing them, as given by Binney, with those at Crosby as ascertained by myself, I find that at Crosby there are fewer Silurians and slates, and more granite and igneous rocks; but the comparison, after all, may be fallacious in this particular. In other respects the nature of the stones is very similar; but if Mr. Binney was correct in saying that in places the clay was one third stones, the preponderance of stones in *quantity* is very marked, as at Crosby the highest proportion measured by me was 1 to 130 †. Mr. Binney's

\* "Notes on the Drift-deposits found near Blackpool," *Memoirs of the Lit. and Phil. Soc. of Manchester*, vol. x. Session 1851-52.

† This is of hand-picked stones; if we include fine gravel that can be separated by washing, the proportion of stony material will be very much larger. (See Mr. Robertson's report appended.)

was no doubt a very rough guess ; my attention was not particularly drawn to this point when I examined the Blackpool section.

The sand-and-gravel beds, G, contain most of the shells that have been taken out of this drift (a list is given in Part I.); the gravel appears to lie in lenticular patches in the sand. The shingle is, so far as I could see, all rolled, and contains no scratched stones. The upper clay contains a variety of rounded stones and pebbles and also striated stones ; but these latter are not in the same profusion as in the Boulder-clay about Liverpool.

At Carnforth, near the station, there is a great development of gravel and shingle used for ballast, intermixed with which are large blocks of limestone.

At Grange, in Morecambe Bay, the shore is covered with large glaciated limestone boulders and a few fragments of trap rocks and Silurian slates. The drift from which they have been washed out is decidedly calcareous, and is intermediate in appearance between that in Galway Bay, Ireland \*, and the Lancashire Boulder-clay, inclining to the former.

At Rampside, on the mainland, opposite to Walney Island is a section of Boulder-clay first described by Miss Hodgson. It is of a red colour, very full of large highly glaciated boulders and blocks in great variety—granite, syenite, slate, trap, limestone, grit, &c. ; one of granite measured 7 feet in diameter ; they are imbedded at all angles. Beyond this dome of Boulder-clay, at the further end of a low Postglacial beach, a section of another dome appears ; and contained in this is a not very perfectly developed arch of stratified sand following the contour of the surface pretty closely.

There are not nearly so many stones in this section, though to all appearance it is on the same horizon.

On the railway from Furness to St. Bees, especially as St. Bees is approached, there is a wonderful development of sand-and-gravel Drift of great depth. The railway skirts the coast ; and the Drift appears to lie in hummocks. Coulderton Cop is one of the most remarkable of these sand-and-gravel hillocks.

*St. Bees Cliffs* (fig. 26).—Commencing at the northern extremity of the section, lying against and partially overlapping the Upper Permian sandstone, J, of St. Bees Head is a purple-red clay, K, containing very few stones. Over this, in the direction of St. Bees Head, stretches a banded arrangement of stratified red sand and gravel, L, following the surface-contour of the clay below, and covered with a thick bed of yellow sand, M, containing in places patches of gravel, M' M', and lenticular patches of gravel under the surface-soil. At the end nearest to the Sea Cote Hotel, *m*, the sand is very full of fragments of red sandstone and Silurian pebbles. From this bluff stretches a low patch of ground containing Postglacial deposits, N, with a mound of sand-and-gravel Drift running through them ; and at its southern end the cliff of Drift again commences with a bluff of gravel, O ; this,

\* “Notes on the Scenery and Geology of Ireland,” Proceedings of the Liverpool Geol. Soc., Session 1878-79.

Fig. 25.—Section in Blackpool Cliffs. (Horizontal scale 1120 feet to 1 inch. Vertical scale 112 feet to 1 inch.)

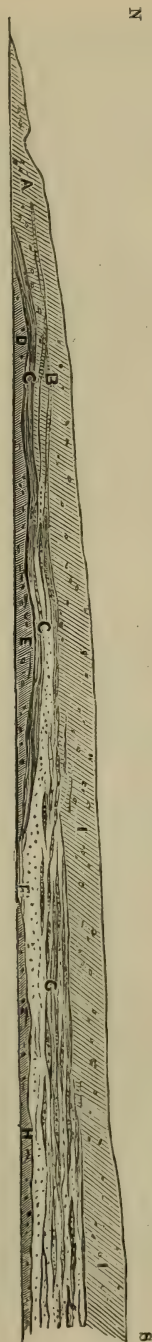
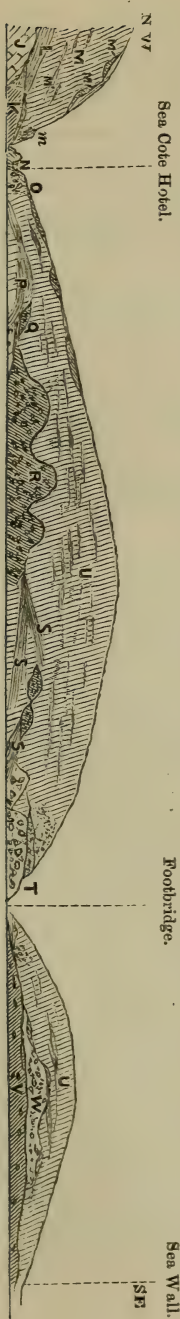


Fig. 26.—Section in St. Bees Cliffs, 1872. (Horizontal scale 1120 feet to 1 inch. Vertical scale 112 feet to 1 inch.)



again, changes southwards into sand of a red colour stratified in an imperfectly arched form, P; lying upon this "haunch" of the arch is a large lenticular patch or pocket of gravel and boulders, Q. A great mass of gravel, with boulders, R, at all angles, now sets in, having a very irregular or contorted surface; this is succeeded by sand with curved laminated bands, S. The southward termination of this cliff, T, at the stream by Sea Mill is a confused mass of huge erratics and boulders thrown about at all angles. Over the whole of the deposits described lies a mass of irregularly stratified sand, U, containing patches of gravel. The highest part of the cliff is about 70 feet above high-water mark.

Southward of the stream another cliff commences; the basement-bed is here along its whole length a red clay, V, with few stones, evidently the same clay as that at the north end of the section.

Lying upon the irregularly arched surface of the clay is an irregular bed composed of sand and gravel, W, full of large blocks of sandstone and other rocks; and overlying this and partially incorporated with it is the bed of irregularly stratified sand with gravel bed, U.

The total length of these sections is about 2600 yards, or nearly one mile and a half.

#### *Remarks on the Coast-Sections.*

The section at Blackpool has long been considered a typical one by those who think they see evidences of a division of the Drift into three important beds each representing a distinct condition of climate. My own section (fig. 25) certainly shows a clay generally of a harder nature than the upper bed, and containing more stones, with a greater proportion of them striated, and separated from the upper by a great development of sands and gravels, which, however, northwards, die into the Upper Clay in a fork-like manner.

If we could see a section further inland, it is highly probable that these two clays would coalesce and shade into each other in places, as, indeed, is shown to be the case in Mr. Binney's section made twenty years earlier. Mr. Binney himself says that his bed No. 2, "a brownish-coloured clay containing stones and so many pieces of limestone as to render it unfit for the purpose of making bricks," is often replaced by stratified beds of sand and gravel. If we confine ourselves to Blackpool, it may be perfectly natural to speak of a threefold division; but the moment we attempt to apply the same classification elsewhere we are met by insurmountable difficulties.

If we are to classify by superposition, the clay at St. Bees will be Lower Boulder-clay; but, unfortunately, it does not correspond in any other way with that of Blackpool, being nearly stoneless. Again, at Rampside, we have two sections side by side on the same horizon, one being full of glaciated stones and answering to the usual description of "Lower Boulder-clay," the other corresponding more with what is called "Upper Boulder-clay;" but in it are the arched beds of sand. There is no evidence whatever that one clay wraps over the



other. The "Middle Sands and Gravels" are supposed by some to represent "Interglacial," and by others "milder" conditions, in consequence of the stones being all rounded and unglaciated. If this be the case, what do the sands and gravels of St. Bees represent? They are even a more distinct deposit, and overlie a lower clay with an eroded surface: but here the conditions are reversed; for the sands and gravels contain in places more and larger blocks than the "Lower Boulder-clay" of Blackpool, and they are full of contortions and evidences of violent action of some sort.

It is noticeable that the Blackpool Drift lies upon an extensive district of the Keuper marls, and Mr. Binney specially notices as "an interesting fact" the "quantity of both granular and fibrous gypsum and waterstone from the upper red marls of the Trias" occurring in bed 4 (the lower clay). I have no doubt that the greater abundance of sands and gravels in the Drift here is due, the first to the abundance of sand-producing rocks in the uplands, and the second, together with the preponderance of stones in the lower clay, to proximity to the mountains of Westmoreland and Cumberland. It is also noticeable that in the neighbourhood of the Carboniferous hills the Boulder-clay possesses a much greater proportion of rocks that have come from these hills.

At Carnforth the shingle and large blocks partake of the nature of the rocks of the valley in which they are situated.

At Grange we have another striking instance of the effect of drainage-lines on the nature of the Boulder-clay; for here it is richly calcareous, being largely made up from the Mountain-limestone rocks of the valley of the Kent.

At Rampside the Boulder-clay overlies Permian rocks; and it is also far from improbable that the Keuper marls may extend from Fleetwood across Morecambe Bay in that direction.

At St. Bees the lower clay has that purple hæmatitic colour which would lead to the belief that its origin has been local; and the sands and gravels evidently have been formed from the detritus of the Permian and perhaps Carboniferous sandstones mixed with that from the Silurian mountains of Cumberland.

#### DRIFT OF THE NORTH COAST AND MOUNTAIN-DISTRICT OF NORTH WALES.

At Colwyn is a ballast-pit used by the Chester and Holyhead Railway: a very great amount of material has been taken out of it. I examined it in 1872 and again in 1874. In descending order is a bed of yellowish-white clay and shingle, from 2 to 3 feet thick; red brick-clay with blue facings and containing only a few stones, about 12 feet; gravel and shingle-ballast, about 25 feet; yellow stratified sand not bottomed, tested to 20 feet deep.

These dimensions will not by any means hold good over the whole area, as by a comparison with my notes in 1872 it appears that the clay lies in lenticular patches interbedded or wedged in with other strata. The stones of the ballast are all rolled; and among them are granites, most of the stones being of local Welsh rocks.

At Llanfairfechan, on the banks of the river, at about 100 feet above high-water mark, there is a section of Till, containing large angular, subangular, and rounded stones imbedded in a matrix of cream-coloured clay; some of the stones, I noticed, were faintly striated, and others ground flat. They appear to be all local felstones, porphyries, and greenstones. The river, at times, is very furious, having a rapid descent, and carries down large blocks of stone. A few years before 1874 it piled up a mass of stones against the railway-bridge and broke one of the cast-iron girders. On the top of the Till was a patch of gravel and shingle; considerably above this and on the western extension of a moraine-like mound is a gravel-pit (*b*, fig. 27) showing current-bedded and contorted laminations like the gravel-pit which will be described at Bangor. The mound is very steep on the north and west sides. Crossing this gravel mound we came upon the river again, which has cut cliffs (*E*, fig. 27) I should judge to be about 80 feet high out of a deposit of current-bedded sand, gravel, and shingle which fills the valley. Higher up the river this deposit appears to rest upon the Till; and the same appears to be the case lower down (as at *F*, fig. 28). There is an immense deposit of sand, gravel, and shingle in this valley. I could find no shells in any of these deposits.

Fig. 27.—Section above Llanfairfechan.

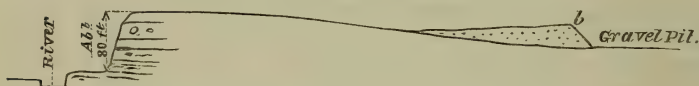
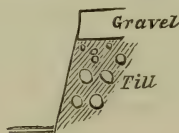


Fig. 28.—Section of Cliffs lower down the River than fig. 27.



At Penmaenmawr, in an excavation made to repair the sea-retaining wall of the railway, I noticed, lying upon the slate rock, a brown clay in which was imbedded a boulder of felspar porphyry; over this was a thin bed of green clay, then a bed of yellow clay.

Ascending the valley at Aber, we find that the gorge where two streams meet is swept pretty clear of Drift; but above this there is a great deposit of Drift, which rises rapidly, apparently in a series of benches, towards the cascade, where the Drift becomes very stony, being mostly shingle and boulders of local rocks—porphyries, greenstones and felstones. All the way to the head of the valley the rocks are Silurian shaly slates. There are a great many greenstones and other boulders of great size lying on the sides of the valley, usually where it is denuded of Drift; but none that I saw were

glaciated. It is a curious fact that so few stones are glaciated in these upper valleys, and so many in the lowlands. The slaty rock of the hills on either side protrudes in great splinters and pinnacles, showing that if it ever had been smoothed down by ice, great denudation has since taken place. The Drift in the gorge consists of clay and stones. It is evident that a tremendous amount of Drift has been removed by denudation.

At Bangor, west of the station, the railway-cutting shows laminated current-bedded and contorted gravels and sand lying upon the upturned edges of the Silurian rocks; in places at the base is packed angular débris, and there are some beds of laminated clayey loam in the gravel. These laminated clays are also to be seen in the ballast-pit below the station.

At Ogwen Bank in the bed of the Ogwen are magnificent glaciated corrugations in the direction of the stream; but they are disconnected, as if the stream had roughly quarried out some of the rock between. Further up the stream is an inclined flank of slate rock splendidly polished, with perfectly straight and parallel striations running across it diagonally; and lying against this rock is a laminated contorted gravel-drift containing large blocks at the base. On the opposite side of the stream this gravel-drift is overlain by a grey Drift containing angular pieces of slate and also rounded boulders, and over all is a cover of alluvium.

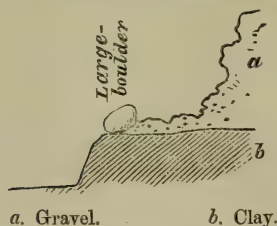
East of Beaumaris, near the Menai Straits, is a cliff of Boulder-clay, of a brownish grey colour generally, containing large boulders, and capped with a reddish clay with pebbles from a great variety of rocks. The Boulder-clay contains a great many large Mountain-limestone blocks, some being smoothed and glaciated. Shell-fragments are also to be found, but sparsely. Beyond this section, towards Puffin Island, are several lower cliffs of Boulder-clay.

On the railway by Menai Bridge station, in a cutting for a siding, in 1872, lying upon a shaly rock of the Carboniferous series was a black laminated band, then a yellow one, and over this a grey-coloured laminated band, all composed of fine scales of shale beautifully arranged in laminæ. Capping it all was a Boulder-clay, varying in colour from brown to yellowish white and blue, evidently from the Carboniferous shales and clays. Near Menai Bridge, and on the level of the last section, was a brown clay containing large angular blocks of a coarse gritty sandstone (Carboniferous).

The railway from Caernarvon to Pen-y-Croes, soon after leaving Caernarvon, is cut through a boulder-drift entirely composed of stones. At Dinas there is a cutting, about 24 feet deep, through Boulder-clay very full of stones; and from this place to Pen-y-Croes are frequent cuttings in Drift composed wholly of boulders and gravel. At Pen-y-Croes are mounds of fine sandy gravel; and a further inspection shows that there is a broad expanse of gravel cut up by streams into undulating outlines and mounds, filling up and spreading round the valley-mouth. This gravel continues across Caernarvonshire to Afon Wen. There must have been a vast denudation to supply all this material together with that which has been washed away.

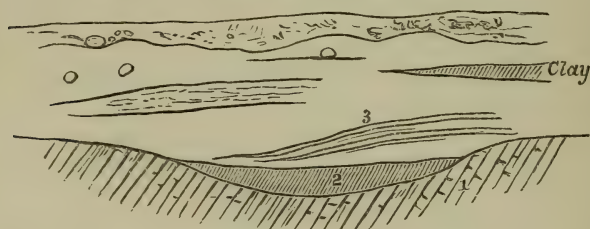
At Brynker station a deep bed of this gravel (*a*, fig. 29) is seen to rest

Fig. 29.—Section at Brynker Station.



upon a clay (*b*), which is to all appearance true Till. It is quite evident that the esker-like mounds of gravel have been cut out of a vast plateau of Drift. Moel Tryfaen, so celebrated for the marine shells first found by Mr. Trimmer on its summit, is a rounded mound-like plateau, forming a spur of Snowdon. It is evident that the Tryfaen gravels are but an upward extension of those on the valley. Lying on the slate rock of the Dorothea Quarries, Nantley valley, in 1872, I noticed the following section (fig. 30)—purple slaty drift (2) lying on the slate rock (1) in a thin patch, and over it laminated current-bedded gravels overlain by a coarse gravelly drift (3), the total thickness in the deepest part being about 45 feet.

Fig. 30.—Section at Dorothea Quarries.



1. Slate rock.      2. Purple slaty drift.      3. Coarse gravelly drift.

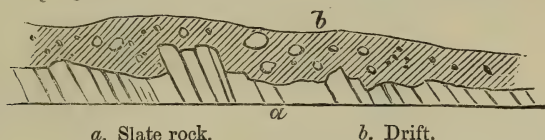
Ascending from Pen-y-Orredd, you pass over the shoulder of Tryfaen; many sinkings for new quarries were being made, which showed a great thickness of drift. There are no terraces on Tryfaen. At the Alexandra quarry, just on the summit, is a bed of current-bedded laminated sand and gravel containing large boulders. At about 12 feet from the surface I took out a glaciated stone; the rolled gravel contains travelled granite and even flints. The larger stones appear to be local. The Drift has been described by Lyell: it lies upon the eroded edges of the slate rock; and from it Mr. R. D. Darbishire, F.G.S., collected the shells a list of which is given in the table, Part I. of this paper. The level is roughly 1400 feet above the sea.



In the cuttings of the railway from Bettws up the Dolwydellan valley, which I inspected in February 1876, while under construction, small patches of stratified gravel are here and there intersected; but, as a rule, very little drift was met with. About three quarters of a mile from Bettws a cutting in the slate rock disclosed a singularly smooth surface which had been protected by a cover of drift; it was not planed down, but was in undulating dimples and hollows, smoothed as if ground with polishing paste. This was very instructive, as where the rock was unprotected by drift on the same shoulder, close by, without any transition, the rock was jagged and irregular.

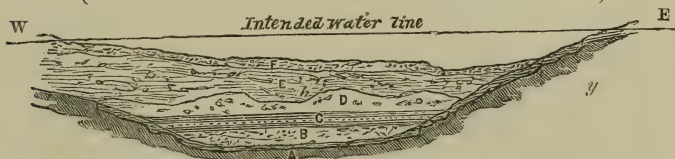
On a rock near to the mouth of the tunnel, but not on the line of railway, towards the summit-level of the railway, some singular markings were to be seen. They appeared as if gouged out at all angles; I have never seen any thing like this before or since.

Fig. 31.—Section on the Rivals Mountain.



In inspecting some excavations made for a sett quarry near the Rivals mountain, I was struck with the jagged nature of the rock underlying the drift (*a*, fig. 31), the very antithesis of that I have described near Bettws. The drift *b* was compact and solid argillaceous matter or Till, full of rough stones intermixed with angular and subangular ones: some of the stones were erratics; but most consisted of the local felstone porphyry. I must bring this account of the Welsh drift to a close by a description of the section disclosed by the excavation of the puddle-wall of the Rhyl Reservoir\* (fig. 32).

Fig. 32. Rhyl Reservoir, Nant Uwydd; section of puddle trench. (Horizontal and vertical scales 220 feet to 1 inch.)



Here we have:—

A. Bed rock, Denbigh Shales, getting more slaty in structure towards *y*. The floor is quite level; but the beds dip up the valley at an angle of about 12°. The sides are stepped.

B. Fine waterworn gravel, angular and larger near the bed-rock.

\* I am indebted to Mr. H. C. Beloe, the engineer of the works, for this in formation.

C. Bookleaf clay, greyish brown in colour, containing a level bed of sand (shown by dotted line). The beds are perfectly level, containing no stones or gravel. The interlaminations were as if dusted with sand as fine as emery powder.

D. Brown clay of very fine texture; it contained some few glaciated blocks of white limestone. The top of the bed is irregular.

E. Blue clay, powdery, full of slate fragments, some long and polished like a hone, most of them much striated along their longer axis. No limestone was found in this bed. The junction with the bed below is obscure; one shades into the other. Nodules were found in this bed. A patch of white clay with gravel occurred between the brown and blue clay at *h*.

F. Alluvium composed of the washings of all the other beds. A cutting in the direction of the valley to drain the brick-croft, showed a rude bedding of pebbles a few feet below the surface. The brown clay in the brick-croft is about 7 feet below the surface; but it varies much in depth, and, I was informed, rested upon gravel. In the alluvium a good-sized oak was met with.

*Vyrnwy Water-works, Oct. 2, 1882.*

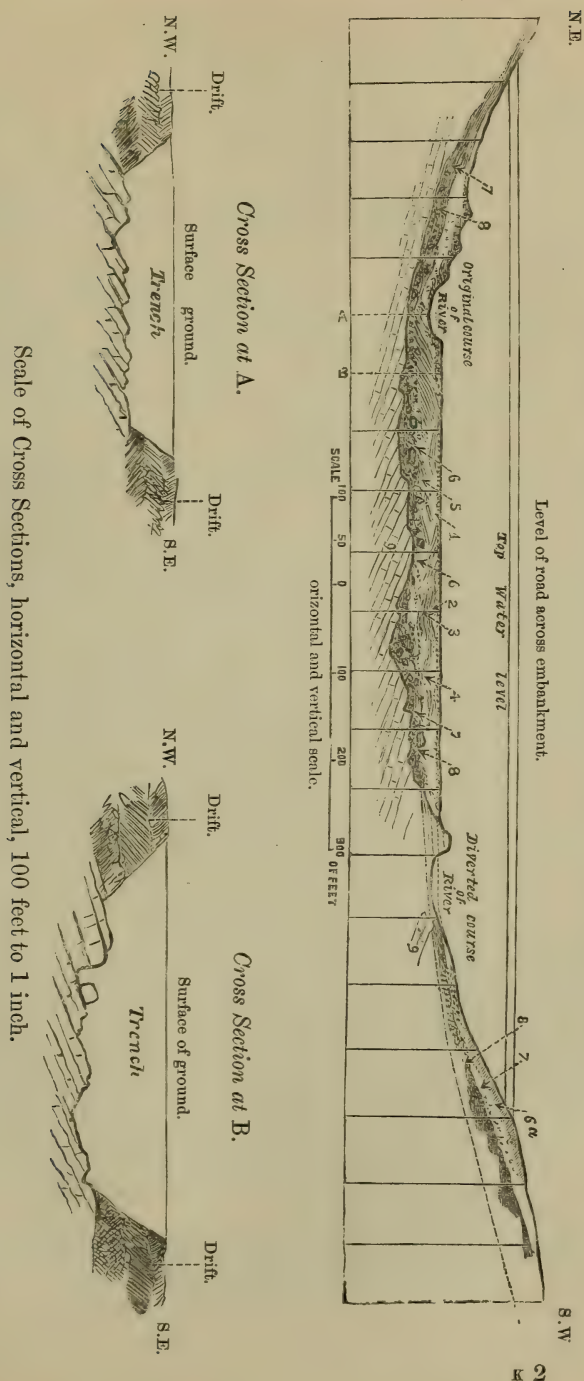
Since the preceding was written, I have had the opportunity of examining with Mr. G. F. Deacon, joint engineer with Mr. Hawksley, the trench excavated for the construction of the masonry dam of the Vyrnwy reservoir which is to supply Liverpool with water. It is not exactly in the district I am describing, as the watershed really contributes to the supply of the river Severn; but I give a description of it as helping to throw light upon the subject of the mountain-drift.

The trench, when I saw it (Sept. 28 and 29), was opened out across the valley through the drift to the rock about a distance of 700 feet, or the whole way across the bottom of the valley (fig. 33). The trench was over 120 feet wide at the bottom—an open cutting without timbering; and such an opportunity of examining a valley-section may never occur to me again.

The river Vyrnwy is one of the affluents of the Severn; and the gathering-ground above the dam, about 7 miles S.E. of Bala Lake, contains 23,500 acres. The valley above the dam is remarkably flat-bottomed; for with 80 feet depth of water at the dam a lake of 1115 acres area and 5 miles long will be formed. The bottom of the valley opposite the Hirnant tunnel, which is to tap the intended lake, is 760 feet; and the top water of the lake will be 825 feet above ordnance datum.

But one of the most interesting facts made evident by the works is that the alluvium and Drift forming the plain of the valley lie in a true rock-basin; for borings through these deposits proved that the rock inside what will ultimately be the lake or reservoir, is considerably below any part of the rock in the bottom of the trench.

Fig. 33.—*Section of Trench for Masonry Embankment, Ynyny, 1882.*



*Description of Section (fig. 33).*

## Down valley side of trench.

- No. 1. Alluvial gravel and shingle.  
 2. Gravel.  
 3. Interlaminations of clay, sand, and gravel.  
 4. Gravel cemented together with iron oxide.  
 5. Shingle and gravel confusedly bedded.  
 6. Shingle and gravel, and Tilly matter intermixed with angular, rounded, and well waterworn boulders of considerable size. In places it contains large masses of slaty rock up to 100 tons weight, torn from the valley-bed.  
 6a. Similar material at side of valley.  
 7. Grey Till.  
 8. Blue hard Till containing angular and subangular boulders, mostly of the slaty rock of the valley. It is much more perfectly developed on the sides of the valley than in the bottom of the trench. There are, I believe, in this Till, as well as in Nos. 7 and 6, grits that have come from the mountains at the head of the valley. Some of the stones are scratched and striated, but not nearly so distinctly as those found in the Low-level marine Boulder-clays.

The opposite side of the trench shows a somewhat different arrangement of the preceding beds, due apparently to currents, some of the arched beds of sand and gravel sweeping from near the bottom of the trench to the top.

- No. 9. Bed rock (summit of Llandeilo); a blue slaty rock with no proper cleavage; dip, measured on a plane of bedding 20 feet square,  $38^{\circ}$  N.W. The beds cross the bottom of the trench diagonally. Huge blocks have been displaced from their beds, and pushed up the plane of the bed below, leaving a cavity at the joint through which a man might walk. The mode in which the rocks have been forced out gives a jagged appearance to the bottom of the trench; but the angles and asperities have been worn off, and there is a *roche moutonnée* in the middle. The striations are not very marked; they run magnetic N. & S. Mr. Deacon informs me that in cutting the trench at the side of the valley for the temporary diversion of the river a mass of rock of 300 tons weight was met with resting upon the rock below and imbedded in drift.

Cross sections A and B (fig. 33) exhibit accurately the form of the rock surface at the bottom of the trench. Their direction, of course, corresponds with that of the valley, the beds dipping the opposite way to the slope of the valley.

*Remarks on the Welsh Sections.*

The effect of the nature of the rocks in each drainage-basin on the character of the drift in the same basin is quite as conspicuous in the examples I have quoted in Wales as it is elsewhere. The sands and clays of Colwyn are evidently derived from the Triassic rocks of the Vale of Clwyd. At Llanfairfechan and Aber the drifts, entirely different from that at Colwyn, are no less clearly traceable to the rocks of the valleys in which they respectively lie, the arrangement and size of the boulders and the character of the drift being also affected by the steeper gradients of the mountain-streams and slopes. Near the coast-level the Drift usually partakes more of the character recognized as marine.

*Distribution of the various kinds of Rock-fragments throughout the Drift, and the Light they throw upon it.*

With the kind assistance of Professor Bonney I have been enabled



to trace with a high degree of probability several varieties of rock-fragments back to their places of origin.

The Eskdale granite\* is found in almost every position and at almost every level, from the Low-level Boulder-clay of the plains of Lancashire to the summit of the Moel Tryfaen in North Wales. It occurs both in large blocks and in rounded pebbles. It is found on the Macclesfield Hills and in the whole of the deposits skirting the coasts from Liverpool to Ulverstone, over a large part of Cheshire, and in the drifts skirting the coast of Wales.

The syenite from Scale Force, Buttermere, is also of pretty general distribution; I have found it in most of the localities about Liverpool, and in considerable blocks on the hills above Poynton and Macclesfield, up to 1200 feet above the sea-level at the Bow Stones.

The Carrock-Fell syenite is a very probable identification. I have found it in several localities about Liverpool.

There are also porphyritic felstones, probably from dykes by Scawfell. There is a large residuum of rocks of the Silurian series, which, though not individually traceable, assuredly largely came from the Lake district; and a remaining series of rocks, granites, felstones, diorites, and Old Red Sandstone, that probably have come from the south of Scotland. Although it is thus seen that the individual identifications are only of different degrees of probability, the igneous and sedimentary rocks below the Carboniferous series, as a whole, are preponderatingly from the Lake district. The Carboniferous rocks, looking at the proportions in which the various members occur, and comparing them with those found in the Drift in the Ribble valley and the valley of the Kent, are unmistakably from the Carboniferous rocks forming the great Penine chain to the north and north-east of the actual localities in which the drift-specimens are found.

Mr. Patrick Dudgeon of Cargen, Dumfries, has kindly gone over the rock-specimens which both Professor Bonney and I suspect came from the south of Scotland. He has identified eight of the specimens of grey granite as certainly from Criffel. This granite contains crystals of spheene and allanite; and he is not aware that these minerals occur in any other granite nearer than Aberdeenshire and Sutherland. The Dalbeattie granite is very similar in composition, as regards the proportions of hornblende, mica, and felspar it contains; spheene crystals are also found in it, but not allanite. One of the specimens is of a granite found at Kirkconnel, about seven miles south of Dumfries. Five other specimens he considers probably to be Criffel. Three specimens probably came from granite-veins found in the district. Some of the Old Red Sandstones and Silurian rocks he considers very probably came from the district about Dumfries; but they are more difficult to identify†.

\* Mr. Mackintosh was the first to trace the Eskdale and Criffel granites over a large area.

† Mr. Goodchild mentions the occurrence of granites from Dumfriesshire and Kircudbrightshire in the Eden valley (*Q. J. G. S.* 1875, pp. 66-7); also of Carrock-Fell and Buttermere syenite (*ibid.* p. 81).

The Triassic sandstone, Keuper marls, and fibrous gypsum, as a rule, cannot have travelled very far; but I have one or two sandstones that may have come from St. Bees.

I have found one or two pieces of what appears to be hard chalk; and there are occasional flints found in the drift, and even on the top of Moel Tryfaen. One flint pebble I took from the Boulder-clay in Sefton Park is reduced to a plane at one end; but whether this is the effect of grinding I cannot tell. It appears most probable that these have come from Antrim.

If these identifications are correct, it will be seen that all the stones are confined to the basin of the Irish Sea and the river-basins flowing into it, excepting some stray stones that may have come from the Highlands of Scotland. It seems curious that such little patches of granite should have yielded such a harvest of blocks; but it is noticeable that the largest patch, viz. the Eskdale, has furnished the greatest quantity. Probably the reason why the granites, syenites, and other igneous rocks occur in a larger proportion in the Drift than would seem to be due to the area they cover *in situ*, is that they naturally break out in larger blocks, and, moreover, they are generally found at a high level.

No Shap-Fell granite has ever been found by me; nor have I ever heard of its being found on the west side of the Penine chain—another fact proving that the erratic rocks of the area under consideration are confined to the drainage-basin of the Irish Sea. This fact seems to me fatal to the idea of an ice-sheet overriding the great watersheds, and points to a system of glaciers radiating from mountain-nuclei. The distribution of the erratics, as described, seems unaccountable on any theory excepting that of their being sea-borne.

### CLASSIFICATION AND CONCLUSIONS.

It now remains to consider the bearings of the facts I have detailed, and to attempt to account for the varied and complicated phenomena they present.

The first part of this paper was published in February 1874; so I think it will be readily conceded that whatever errors may attach to my views are not due to the haste with which they have been adopted.

As my desire throughout has been to form my opinions from the facts as seen by myself, while studying the many very valuable contributions that have appeared from other observers, I have purposely adopted a system of natural description rather than of geological labelling, so that I may place my readers as nearly as possible in my own position.

### PRE-DRIFT SURFACE OF THE LAND.

I must distinguish the Pre-drift surface of the land from the Pre-glacial: the former is the surface form of the rocks if the drift-covering were removed; the latter is to a great extent a matter of supposition.

In every case, without an exception that I can remember, other than in the gullies presently to be described, wherever in the neighbourhood of Liverpool the covering of Boulder-clay has been removed, and the underlying rock has been of a nature capable of receiving and retaining such impressions, I have found it planed and striated. The striations are more or less in the direction of north-west, ranging usually from N.  $40^{\circ}$  W. to N.  $15^{\circ}$  W.\* It certainly seems as if an immense mass of ice had moved continuously over the country; and though the theory of an ice-sheet radiating from the mountain-districts of Cumberland presents the most feasible explanation, yet it is not without its difficulties; so that some local geologists are inclined to revert to the iceberg and field-ice theory for an explanation.

The portions of the rocks that have no cover are weathered, eroded, and worn down to a very considerable extent. But the most interesting feature of which we have proof is that the surface-form of the Drift does not always give an indication of the surface-form of the rock beneath. I have already described the Preglacial valley of the Mersey; and it is difficult to resist the conclusion that, if we could lay bare the beds below the Irish Sea, we should find a system of river-beds ramifying and uniting into one great river discharging into the Atlantic; and it is quite possible that this may have discharged northwards, between Scotland and Ireland, as there is off the Wigtonshire coast, in the words of Captain Beechy, "a remarkable ditch, upwards of 20 miles long by about a mile only in width, in which the depth is from 400 to 600 feet greater than the general level of the bottom about it." These facts are quite in consonance with the relations of the British Isles to the continental area of Europe. We are on the edge of a great plateau; and every valley and mountain on the western coast of Scotland, where they touch the sea, gives evidence by its outline that the country has been submerged. If we pass over to Norway the same holds good; every thing points to a former and Preglacial or Glacial greater elevation of the country; for the gullies which I have described cut out of the solid Triassic rocks could have been worn down by naught save subaerial river-action; and to get this a very considerably greater elevation must have obtained. It will have been observed that the bottom of the buried gullies, where they have been examined, as at the Rivington Reservoir, on the Yarrow, in the North Docks and the Rhyl Reservoir, all show the action of running water, not that of ice.

When I took the Liverpool Geological Society over the North-Dock excavations in 1876, Mr. Lyster, the engineer, drew my attention to the remarkable evidence of water-action on some of the rocks at the bottom sloping towards and flanking the river.

It has long appeared to me, from the facts I have observed, that the period of greatest glaciation was one of considerable elevation.

\* A list of glacial striæ found in S.W. Lancashire and in Cheshire is given by Mr. G. H. Morton, F.G.S., in the Proc. of Liverpool Geol. Soc. 1876-77, pp. 292, 293.



The existence of these riverine gorges in the solid rock so far below the present level of the sea is as certain a proof of former elevation as the marine beds on the top of Tryfaen are of depression. All the surrounding facts lend force to and consolidate that conclusion. If this be so, it is the more easy to understand the existence of a snowfield on what are now plains little above the level of the sea.

If there ever existed this extension of ice from the mountain-centres (for I have observed no facts to warrant in the slightest degree the idea of a Scandinavian ice-sheet extending over our island), it must have melted back and separated into local glaciers before the drift-deposits I have described were laid down. During the progress of the great submergence it is as clear to my mind as any thing can be in so difficult a geological subject, that no ice-sheet existed in any part of Lancashire that I have examined\*.

I have studiously confined these speculations well within the boundary of personally ascertained facts.

#### RED SAND AND RUBBLE DÉBRIS OF THE TRIAS.

When the underlying rock is not planed and striated, it is usually covered with broken rock and packed rubble, graduating into red or yellow sand, according to the colour of the rock beneath. In no case that I have seen (and I have devoted much attention to this point), where the sand is undisturbed, does it contain any erratic pebbles or stones, nothing more than a half-imbedded boulder. In some cases a considerable amount of this sand is stratified and evidently rearranged by sea-action; and it then may contain both shell-fragments and erratic stones. In the description of the section at Bootle-Lane Station (Part I. p. 27), I have called this sand "Ground-moraine equivalent of the Scotch Till." At the time it was written I had not seen the Scotch Till, but have since had the good fortune to see a section in the new Cartdyke Dock, Greenock, of the "Till" resting upon red sandstone of the Calciferous series, in which the red sand and rubble is interposed between the rock and the Till in a manner precisely similar to what occurs between our marine Boulder-clay and the Triassic rocks†.

That this formation is the product of land-ice, I think is the most feasible supposition, though this explanation is not without its difficulties, as the same sort of beds sometimes arise from subaerial decay. But I cannot conceive how icebergs or field-ice alone could have so universally polished the rocks of our Lancashire plains, seeing that, if so, it must have been done on a sea-bottom covered with Boulder-clay, sands, or gravel. Nor have I in one single instance with the most careful search found any disturbance in these red

\* The late Mr. Clifton Ward has expressed views on the glaciation of the Lake district, with the moderate character of which I am disposed to agree. (See Q. J. G. S. vol. xxix. p. 422 and vol. xxxi. p. 152.)

† This is described in my paper "On the glacial Beds of the Clyde and Forth" (Proc. of Liverpool Geol. Soc., Session 1879-80).



sands traceable to any thing similar to the grounding of ice in any form, though they have rested on rock in immediate proximity to a polished surface. As a rule, the Boulder-clay rests upon the sand as if deposited in the most quiet manner.

#### GULLY-GRAVELS.

The ramifications of gullies below low-water mark which I have described as existing in the substratum of rock beneath the Drift are usually filled with rolled gravels.

This is not invariably true, as, if deep, they sometimes contain gravels and sands, or, as in the case of the valley of the Mersey at Widnes, clay. To some extent their presence may be dependent upon the rate of inclination of the bed of the gully. The gravels are of rocks similar to the stones found in the Drift. It is also not an uncommon occurrence to find gravel and shingle resting upon the rock under the Boulder-clay\*, or, more rarely, in patches within the lower clay. It is readily conceivable that, if there was any tendency to the accumulation of gravel on the sea-bottom, it is just at these gullies kept clear by the rush of fresh water down them that we should expect to find gravel and shingle. The invariably rolled character of these stones seems to point to their accumulation at or near "between tides." I have, however, never seen any arrangement of the gravels that could be distinctly described as littoral; probably increasing submergence brought them under the influence of other currents which disturbed what was originally a littoral arrangement.

It is difficult to draw a distinct line of demarcation between these gravels and the Drift above, as in some sections they alternate with beds of sand and clay. At Hooton Station, Cheshire, there was a great depth of them, and also at Fiddlers Ferry, near Warrington. And lately a boring at Halewood, about  $\frac{3}{4}$  of a mile from Hunts Cross station, and not far from my line of section of the Liverpool Extension Railway (fig. 6, p. 90), showed a depth of 137 feet of Drift. The surface-level was the 100 feet contour, the bottom bed being gravel 8 feet thick resting on Keuper Marl unbottomed at 417 feet.

They underlie the Boulder-clay in the bed of the Mersey in many cases where it has been exposed by dock-excavations, and often show distinct signs of current-bedding. I see no reason to infer that these gravels have been derived from any preexisting Boulder-clay. If they had been, or if the Boulder-clays were *remaniés*, some vestiges of the original Till would surely have been before this discovered. I have searched in vain for it.

#### LOW-LEVEL BOULDER-CLAY AND SANDS.

These represent by far the greatest bulk of the drift-deposits of the north-west of England. It was to these beds that my attention was at first more particularly directed; and in Part I. I have described

\* The excavations of the Atlantic Docks proved that these gravels lie in stream-like patches on the rock (see plan of Docks, p. 86).

a typical section at Bootle Lane, as well as given a list of the shells and shell-fragments found in them by me, amounting to 44 species; this list has been increased by Mr. Shone by his finds at Newton, Cheshire, to 56 species; 16 species of Foraminifera were also determined by Mr. D. Robertson of Glasgow, out of one sample of clay I sent him. Ostracoda also occur, and other minute *reliquiæ* of the sea\*. My object in these preliminary investigations was to ascertain if there were any organic remains by which the drift-beds might be separated into geological horizons—because, if, as some maintain, two glacial and one interglacial period are represented in these beds, there ought to exist, *a priori*, some decided distinction in the molluscan fauna. I utterly failed to detect any; nor is it maintained that any subsequent observations have succeeded, though the observers have been many and zealous, and only anxious to make the discovery.

The *facies* of the fauna is of a more northern character than that of the existing Mollusca of the British seas, the *typical* shell being *Astarte borealis*, which I found in almost all the localities, though *Turritella terebra* is the most abundant.

I do not place much reliance upon the palæontological evidence in this case, either as determining age or climate. The Clyde laminated brick-clays contain an assemblage perhaps more distinctly northern than that of my list; yet these laminated clays can scarcely be considered other than Postglacial, and are certainly of a date long posterior to the beds I am now describing. I have therefore ceased to attach much value to this kind of evidence unless backed up by facts of another and more complete kind†.

The most distinct and reliable signs which justify us in calling these beds Glacial are the numerous striated and planed erratic blocks, boulders, and pebbles they contain. I have made a large collection of these included rocks from various localities in the neighbourhood of Liverpool‡.

These various rocks occur promiscuously through all the beds of the Low-level Boulder-clay, their proportions changing in different localities; so that I have found it impossible to separate the beds by the included stones.

In the Drift of the upper part of the Ribble valley an order of arrangement vertically may be made out, as I have already described, but never in the true sheet of Low-level Boulder-clays and sands. The larger blocks (say, weighing upwards of a ton) are usually fluted in the direction of their longer axes, and are convex in cross section.

\* And in 1882 in samples of clay sands and gravels from the North Docks and Atlantic Docks, described by Mr. Robertson in the Appendix.

† Mr. Searles Wood has brought forward considerable evidence to prove that the east-coast beds are older than the west-coast deposits; but my faith in the inferences drawn from the contained shells is much shaken. The east-coast glacial deposits are much more disturbed than most of those described in this paper. On the other hand the erratics of the west coast are more distinctly planed and striated.

‡ Much valuable information on the subject is to be found in Mr. Mackintosh's paper "On the Limits of Dispersion of the Erratic Blocks of the West of England," Quart. Journ. Geol. Soc., 1879, pp. 425–455.

Smaller boulders are often ground to a perfectly true plane, and sometimes without striations. In others the stone presents several distinct planes or facets with striations meeting in a herring-bone fashion; others are irregular in form and indefinitely scratched all over as if bumped about, or rolled over, under ice. Sometimes boulders occur aggregated in nests or pockets in the clay.

It is quite evident that these stones have never been disturbed since they were dropped in the mud of a glacial sea\*.

The proportion of the contained stones to the bulk of the deposit varies very considerably. Some of the clays are decidedly stony; and others consist of a great mass of unctuous clay with very few stones, but with a large percentage of fine gravel intimately intermixed with it. Probably half of the stones taken out of the clays in the neighbourhood of Liverpool used for brick-making are more less scratched; and it is worthy of remark that by far the larger proportion of the examples I have collected of specially well glaciated stones are Silurian grits or other old rocks from the mountain-districts. But in beds of gravel and sand the stones are usually rounded. This, however, can hardly be an evidence of an interglacial climate; for we find in many cases, as I have detailed, that the lower and harder beds of the clay often, nay, generally contain more rolled stones than the upper or middle. Such is the case at Dawpool; and it was so in the Atlantic Docks, Liverpool. At Blackpool, on the contrary, according to Binney, the lower and harder beds contain the greatest number of striated stones.

It is therefore clear that these distinctions cannot indicate climatic differences.

And if this be admitted, can we on these grounds consider the lower bed of Boulder-clay as a geological subdivision? The true explanation seems to be that these stones have been rolled on the beach before being finally deposited on the muddy bottom of the Glacial sea. When beds consist solely of gravel, boulders, and shingle, that, in itself, is a proof that either tidal currents or shore-conditions have prevailed in the places where they have been laid down, or that they have been at a depth no greater than where the wind waves can act upon and move them.

The absence of stones in some of the sand, as in the section described by Mr. Shone, near Chester, it appears to me, can be accounted for in this manner. Beds of clay must necessarily be very slow accumulations. Beds of sand, on the contrary, within reach of the tide are constantly moving; as an illustration, the banks and channels in the estuary of the Mersey are constantly being surveyed and the changes marked by buoys by the marine surveyors.

Hundreds of thousands of tons will be shifted by a single gale. If there were floating ice conveying stones and depositing these in the estuary now, what would be the effect? They would be sorted by the currents, we should have shingle in one place, sand only in another,

\* Dr. James Geikie has expressed the opinion that these deposits are sea-bottoms ploughed up by land-ice ("The Intercrossing of Erratics," reprint from the 'Scottish Naturalist').



and in some sands and gravels. It must not be lost sight of that, during the submergence and emergence of the land, every river-valley at every point has been at one time or other an estuary. To expect under these circumstances all beds to be similar would be to expect that which could never happen. Sand is found in pockets in the Boulder-clay as well as in horizontal beds; and these often assume very curious shapes; they also seldom contain stones, though the clay surrounding them does.

The sands and gravels at St. Bees which are in great force are distinguished by contorted bedding, confused aggregation, and the great number of included blocks and boulders. The shingle, gravel, and sands are intruded or folded into each other. The underlying clay is peculiarly free from stones. If we found geological subdivisions on such grounds, what are we to do with these beds? No one has even suggested an explanation.

As assisting to explain these Low-level Boulder-clays and sand beds so puzzling to observers, I may here state that I have not seen in the whole series one single example of well-defined shore-conditions. No continuous section of any length ever displayed the horizontality distinguishing most littoral deposits. They are all more or less arched, as my sections show; this is especially remarkable where continuous thin beds of sand like that near Farnworth extend for a long distance. I infer from this circumstance, as well as from certain collateral peculiarities already described, that the beds from base to summit substantially represent a sea-bottom, the conditions of depth altering as the land slowly subsided or reemerged.

It is the circumstance that the beds represent conditions that are not within our ken, as littoral deposits are, that has, I believe, led to so much confusion.

In a paper "On Tidal Action as a Geological cause" (Proc. of Liverpool Geol. Soc., 1873-74), a collateral investigation I felt it incumbent on me to make before I could properly attack the problem presented by the Glacial beds, I have shown that the tide-wave, unlike the wind-wave, acts at the greatest depths; and among other examples I have quoted that of the excavation or keeping open of the "ditch" before referred to opposite the coast of Kircudbrightshire. Other examples of almost equal force could be given. My conclusions are that the long continuous beds, to some extent arched, are the effects of tidal arrangement below low water; the horizontal laminations of the clay occasionally met with I attribute to the same cause, and the short arched book-leaf laminations also.

I have shown in Part I. that the shell-fragments found distributed through the clay are, as a rule, only of such a size as a moderate current could convey. The much-contorted and cross-laminated beds of which the St. Bees sands and gravels are the best examples, I am of opinion were laid down partly above and partly below low water, like our estuary sandbanks within reach of the wind-waves.

It is also quite evident that as the depth of the sea changed the direction of the tidal currents would change also. Thus what was a hollow in clay might become filled with sand, which, again, might



have clay laid upon it as the bottom further subsided. Or in the direction of the greatest rush of the tide shingle might form, as is the case now in places in the bed of the Irish Sea and English Channel\*.

Bearing these facts in view, let us see if we can apply them to an explanation of the peculiarities of the deposits I have detailed. The first-formed deposits were undoubtedly the gully gravels and sands; the next were the beds of gravel, current-bedded, lying at the base of the Boulder-clay. As the land further subsided the lower clay began to form, and with it became mixed the red sand washed from the previously degraded Triassic rocks—the mixture of materials being calculated to form a hard, short, red clay. On still greater subsidence these clays would be brought within the reach of cross tidal currents, creating those lines of erosion often mistaken for lines of unconformity representing geological subdivisions; and on this a greater or less bed of sand might or might not be deposited. The deposition of more plastic clays would then set in; but there might be intermediate beds of sand still laid down. At a certain depth of immersion the deposits would reach their maximum, one element being the extent and nature of the land still unsubmerged. But while this submergence was still going on, part of the deposits would be washed in by the sea landwards, to be again redistributed as they came successively under the influence of the waves and tide. When the submergence reached its extreme limit the amount of sediment contributed by the land to the ocean would reach a minimum. As the land rose again out of the waters, something of a similar kind would happen in inverse order, only the rivers would reexcavate the drift which had been deposited in them.

I have already pointed out that the character of each basin is influenced most profoundly by the nature of the rocks within it, so that in different areas or basins diverse beds will mark the same stages of submergence. If I have succeeded in establishing this point, it follows as a natural consequence that the bulk of the drift-deposits of these low-level plains have been formed when the seas were comparatively shallow, probably at depths of from 100 to 300 feet. The shallower the sea the more local the deposits; for as the water-partings of the basins became submerged the nature of the deposits would to a larger extent be due to the mechanical distribution of the tides and waves.

It would occupy too much time to attempt to explain each bed on these principles; but I am fully satisfied they are susceptible of it. If my explanation be correct, it is evident that the successions of beds are local phenomena, and that no geological subdivisions can be founded upon them.

#### MOUNTAIN- AND HILL-DRIFT.

I have before remarked that the distinguishing feature of our

\* "Tidal Action as a Geological Cause," Proc. of Liverpool Geol. Soc., Session 1873-74.

mountain scenery, as relates to our present subject, is, as compared with the plains, the absence of Drift. This, perhaps, seems what we might naturally expect from the Postglacial denudation which it has since undergone. But in the region of lakes we find lakes still; and one would expect that if much material had ever existed in the drainage-basins in the form of Drift, it would in travelling down streams be caught in the lakes; and hence we might expect them to be now filled up. There are no means of estimating the actual amount of material that has thus been entrapped; a series of borings would be required to do this. But I would point out that the whole of the material brought down is not deposited in the lake; on the contrary, we find the shores of lakes pretty generally formed of shingle and gravel. The wind-waves must move this; and doubtless in most cases there is a general progression of materials along the shore, and eventually down stream from the outlet. This may account for some of the material; and the generally limited area of the drainage-basins in mountain-districts will also tend to explain the absence of great quantities of Drift. It will be seen, and it is in accordance with the theory here put forth, that the larger the drainage-basin in which the Drift lies the greater is its quantity. In this way it is that the plains of Lancashire are so drift-covered, while the hilly tracts are to a large extent driftless. The Drift met with in the mountain-valleys I have described is usually either true Till or boulder- and gravel-drift, when found together, the latter usually overlying the former. The Till most probably has been formed under or in front of the local glaciers during their recession.

That the ice lingered longer about the mountains than elsewhere is proved by the iceberg-borne erratics of the Lancashire Boulder-clay. Consequently, while the Drift of the plains was being formed, the greater part, if not the whole, of the materials denuded from the mountains and valleys was pushed forwards by the glaciers and protruded into the sea. I have shown how at the Atlantic Docks the majority of the large erratic stones, deeply grooved and worn, are in the upper bed of plastic clay. The boulders in the lower beds are more frequently rounded. This fact corresponds with what would happen under the sequence of events the theory assumes. The larger stones would not be conveyed away until there was depth of water sufficient for the flotation of the iceberg.

But I have shown that an enormous amount of material has come down from the Welsh mountains in the form of boulders and shingle, which is distributed on the plains into which these valleys debouch; and it is extremely probable that much of it has been moved to its present position during and since the emergence of the land from the sea.

#### CONCLUSION

I fear that my views will not appeal to the imagination in so lively a fashion as do some at present in vogue; but of this I am sure, I have been animated by the sole desire of seeing things as

they are. Complicated and inexplicable as the features of glacial geology are when viewed separately, I have attempted to show that there are recognizable features in common, running through all, that point to geological agents in the past not very dissimilar to those we now witness. Then as now, but from a more limited area proportionally to the amount of submergence, the Thames, the Mersey, and the Severn, and innumerable other streams and rivers, brought down their quota of material to the beds then forming at the bottom of the sea.

## APPENDIX.

*Report on the Sands and Gravels and Boulder-clays and the top Silt, at the Dock F of the Atlantic Docks, Liverpool.* By DAVID ROBERTSON, Esq., F.L.S., F.G.S.

No. 1. Sand- and gravel-bed at the bottom of the section is the most puzzling of the whole, as it contains a few freshwater Ostracoda and numerous fragments of what appear to be marine shells, but so small and waterworn that no character is left by which they can be satisfactorily identified; yet, from various peculiarities of the fragments, I have little or no doubt that they are marine. It is, however, singular that no Foraminifera were detected in it, or organisms that are in most cases present in marine deposits, even where no other animal remains are to be seen.

The material consists, in round numbers, of 70 per cent. of fine sand, with very little mud, and 30 per cent. of gravel. Many of the pieces are distinctly striated and well rounded and polished.

No. 2. The reddish-brown clay of this parcel consists of 60 per cent. of fine mud, 32 sand, and 8 of gravel; about one half of both sand and gravel is more or less angular; the other half is well rounded, and one piece in particular finely striated. Shell-fragments are numerous, but all so small and imperfect that they cannot be identified. The following are the Foraminifera:—

*Biloculina ringens*, Lamk.  
*Triloculina oblonga*, Mont.  
*Quinqueloculina seminulum*, Linn.  
*Lagena sulcata*, W. & J.  
 — *marginata*, W. & J.  
 — *globosa*, Mont.  
 — *squamosa*, Mont.  
 — *hexagona*, Will.

*Lagena melo*, D' Orb.  
*Polymorphina communis*, D' Orb.  
*Bulimina pupoides*, D' Orb.  
*Cassidulina crassa*, D' Orb.  
*Truncatulina lobatula*, Walker.  
*Polystomella striato-punctata*.  
 F. & M.  
*Nonionina depressula*, W. & J.

It is unusual to find so many Foraminifera and no Ostracoda or other marine animal remains.

No. 3. Red muddy sand much waterworn. The organic remains are represented by very small chips of shells, a fragment of a starfish, and one Foraminifer (*Nonionina depressula*).

No. 4. Red clay, consisting of 58 per cent. of fine mud, 20 of sand, and 22 of gravel. No satisfactory striations were detected on any of the pieces, which were mostly small and waterworn. Shell-fragments moderately common. It is rather remarkable that these

shell-fragments are all angular, having no appearance of rolling or rubbing, while the gravel has suffered considerably from abrasion.

## FORAMINIFERA.

<i>Cornuspira foliacea</i> , <i>Phil.</i>	<i>Bulimina pupoides</i> , <i>D'Orb.</i>
<i>Quinqueloculina seminulum</i> , <i>Linn.</i>	— <i>marginata</i> , <i>D'Orb.</i>
— <i>subrotunda</i> , <i>Mont.</i>	<i>Discorbina rosacea</i> , <i>D'Orb.</i>
<i>Lagena globosa</i> , <i>Mont.</i>	— <i>globularis</i> , <i>D'Orb.</i>
— <i>sulcata</i> , <i>W. &amp; J.</i>	<i>Planorbulina mediterranea</i> , <i>D'Orb.</i>
— <i>Williamsonii</i> , <i>Alcock.</i>	<i>Truncatulina lobatula</i> , <i>Walker.</i>
— <i>gracillima</i> , <i>Sequenza.</i>	<i>Rotalia Beccarii</i> , <i>Linn.</i>
— <i>squamosa</i> , <i>Mont.</i>	<i>Polystomella striato-punctata</i> , <i>F. &amp; M.</i>
<i>Polymorphina gibba</i> , <i>D'Orb.</i>	<i>Nonionina asterizans</i> , <i>F. &amp; M.</i>
— <i>lactea</i> , <i>W. &amp; J.</i>	— <i>depressula</i> , <i>W. &amp; J.</i>
— <i>oblonga</i> , <i>Will.</i>	
<i>Textularia pygmæa</i> , <i>D'Orb.</i>	

## ZOOPHYTA.

*Eudendrium ramosum.*

## SPATANGIDÆ.

Spines and plates.

## MOLLUSCA.

Shell-fragments.

No. 5. Silt (Postglacial) consisting of fine sandy mud free from gravel. Fragments and valves of shells common. The following is a list of the various organisms found in the bed :—

## PLANTS.

A few seeds.

## FORAMINIFERA.

<i>Cornuspira foliacea</i> , <i>Phil.</i>	<i>Nodosaria pyrula</i> , <i>D'Orb.</i>
<i>Biloculina depressula</i> , <i>D'Orb.</i>	<i>Polymorphina oblonga</i> , <i>Will.</i>
— <i>carinata</i> , <i>D'Orb.</i>	— <i>communis</i> , <i>Will.</i>
<i>Triloculina oblonga</i> , <i>Mont.</i>	<i>Globigerina bulloides</i> , <i>D'Orb.</i>
<i>Quinqueloculina Candeiana</i> , <i>D'Orb.</i>	<i>Bulimina pupoides</i> , <i>D'Orb.</i>
— <i>seminulum</i> , <i>Linn.</i>	<i>Discorbina rosacea</i> , <i>D'Orb.</i>
— <i>bicornis</i> , <i>W. &amp; J.</i>	<i>Planorbulina mediterranea</i> , <i>D'Orb.</i>
— <i>subrotunda</i> , <i>Mont.</i>	<i>Truncatulina lobatula</i> , <i>Walker.</i>
<i>Trochammina inflata</i> , <i>Mont.</i>	— <i>refulgens</i> , <i>Mont.</i>
<i>Lagena lævis</i> , <i>Mont.</i>	<i>Rotalia Beccarii</i> , <i>Linn.</i>
— <i>gracillima</i> , <i>Sequenza.</i>	— <i>nitida</i> , <i>Will.</i>
— <i>sulcata</i> , <i>W. &amp; J.</i>	<i>Polystomella crispa</i> , <i>Linn.</i>
— <i>interrupta</i> , <i>Will.</i>	— <i>striato-punctata</i> , <i>F. &amp; M.</i>
— <i>globosa</i> , <i>Mont.</i>	<i>Nonionina asterizans</i> , <i>F. &amp; M.</i>
— <i>lucida</i> , <i>Will.</i>	— <i>stelligera</i> , <i>D'Orb.</i>
— <i>hexagona</i> , <i>Will.</i>	
— <i>melo</i> , <i>D'Orb.</i>	

## ECHINODERMATA.

*Ophiuroidea.*

Spines, small and imperfect.

*Echinoidea.*

Spines, fragmentary. Pedicellaria, fragment.



*Spatangidæ.*

Spines common.

*Thyonidæ.*

Spicules rare.

## ANNELIDA.

Pectinaria, sp. ?, fragments.

## CRUSTACEA.

*Ostracoda.*

*Cythere lutea*, Müller.  
 — *albo-maculata*, Baird.  
 — *pellucida*, Baird.  
 — *porcellanea*, Baird.  
 — *castanea*, G. O. Sars.  
 — *tenera*, Brady.  
 — *Robertsoni*, Brady.  
 — *pulchella*, Brady.  
 — *tuberculata*, G. O. Sars.  
 — *villosa*, G. O. Sars.  
 — *concinna*, Jones.  
 — *badia*, Norman.  
*Cytheridea elongata*, Brady.  
*Loxoconcha impressa*, Baird.

*Loxoconcha multifora*, Norman.  
 — *pusilla*, Brady & Robertson.  
*Cytherura cellulosa*, Norman.  
 — *clathrata*, G. O. Sars.  
 — *striata*, G. O. Sars.  
 — *angulata*, Brady.  
 — *cuneata*, Brady.  
*Cytheropteron latissimum*, Norman.  
 — *nodosum*, Brady.  
*Cytherideis subulata*, Brady.  
*Sclerochilus contortus*, Norman.  
*Paradoxostoma variabile*, Baird.  
 — *flexuosum*, Brady.  
 — *arcuatum*, Brady.

## CIRRIPEDIA.

*Balanus crenatus*, Brug.*Balanus balanoides*, Linn.

## POLYZOA.

*Crisia eburnea*, Linn.

*Serupocellaria scabra*, Van Ben., var.  
*elongata*, Smith.

## INSECTA.

Elytra.

## MOLLUSCA.

*Conchifera.*

*Anomia ephippium*, Linn.  
*Mytilus edulis*, Linn., fry and  
 small pearl.  
*Nucula tenuis*, Mont.  
*Montacuta bidentata*, Mont.  
*Cyamium minutum*, Fabr.  
*Cardium edule*, Linn.

*Donax vittatus*, Da Costa, mode-  
 rately rare.  
*Venus gallina*, Linn.  
*Tellina balthica*, Linn.  
*Mactra subtruncata*, Da Costa,  
 small valves.  
*Corbula gibba*, Olivi, a valve.  
*Pholas* sp., a small fragment.

*Gasteropoda.*

*Hydrobia ulvæ*, Penn., var. sub-  
*umbilicata*, Jeffreys, common.

*Aclis supranitida*, S. Wood.  
*Utriculus obtusus*, Mont., one example.

Seeing that the species that prevail most in No. 5, Silt-bed, *Hydrobia ulvæ* and *Tellina balthica*, are generally found most abundantly in muddy estuarine flats, there can be little doubt that the deposit partakes much of that character.

The other Invertebrates in the bed do not disagree with such  
 Q. J. G. S. No. 154.

conclusions. Although not peculiar to such conditions, they are frequently met with in situations more or less brackish\*.

The Boulder-clays differ from our Scottish Boulder-clay (Till) by being fossiliferous and intercalated with fossiliferous beds of sand and gravel.

A fossiliferous section of Boulder-clay that I examined at Knockburn, near Belfast, was much like that at Bootle, being fossiliferous and intercalated with beds of various composition.

#### EXPLANATION OF PLATE V.

Map of the Basin of the River Mersey, and of part of that of the Dee, to show the relation between the Drift and the Rock-structure of the Basins.

#### DISCUSSION.

The CHAIRMAN (Dr. J. Gwyn Jeffreys) said that having examined probably all the Post-tertiary shells which had been recorded from the extensive district under consideration, he had come to the conclusion that none of them were Arctic, but that nearly all were local, with a remarkable admixture of both northern and southern forms. The most peculiarly northern species is *Astarte borealis*, which is not now found living further south than Kiel Bay. The Foraminifera noticed in the paper are all local.

Prof. PRESTWICH asked how river-action could have taken place during the great submergence supposed by the author. He remarked on the great value of the evidence which the sections in this paper afforded of the excavation of many river-valleys in preglacial times, and thus of the higher position of the land.

Mr. BAUERMAN remarked on the value of the work done by Mr. Mellard Reade in watching excavations going on during many years—excavations which would soon be filled in or obscured. He remarked that the fragment of chalk exhibited was more like the Antrim than the English chalk.

Prof. BOYD DAWKINS said that fragments of chalk undistinguishable from that of Antrim are found in Lancashire and as far to the south-east as Ironbridge on the banks of the Severn.

The AUTHOR thought that the non-arctic character of the boulder-clay shells was accounted for by the fact that the severest cold had passed away when they were deposited. At Widnes the river-valley was excavated 140 feet below the present sea-level.

\* This silt is probably the equivalent of the beds underlying the great peat-bed, which the author has named the Formby and Leasowe marine bed. See "Post-glacial Geology of Lancashire," Proc. of Liverpool Geol. Soc., Session 1871-72.



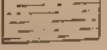
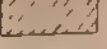

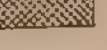

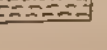



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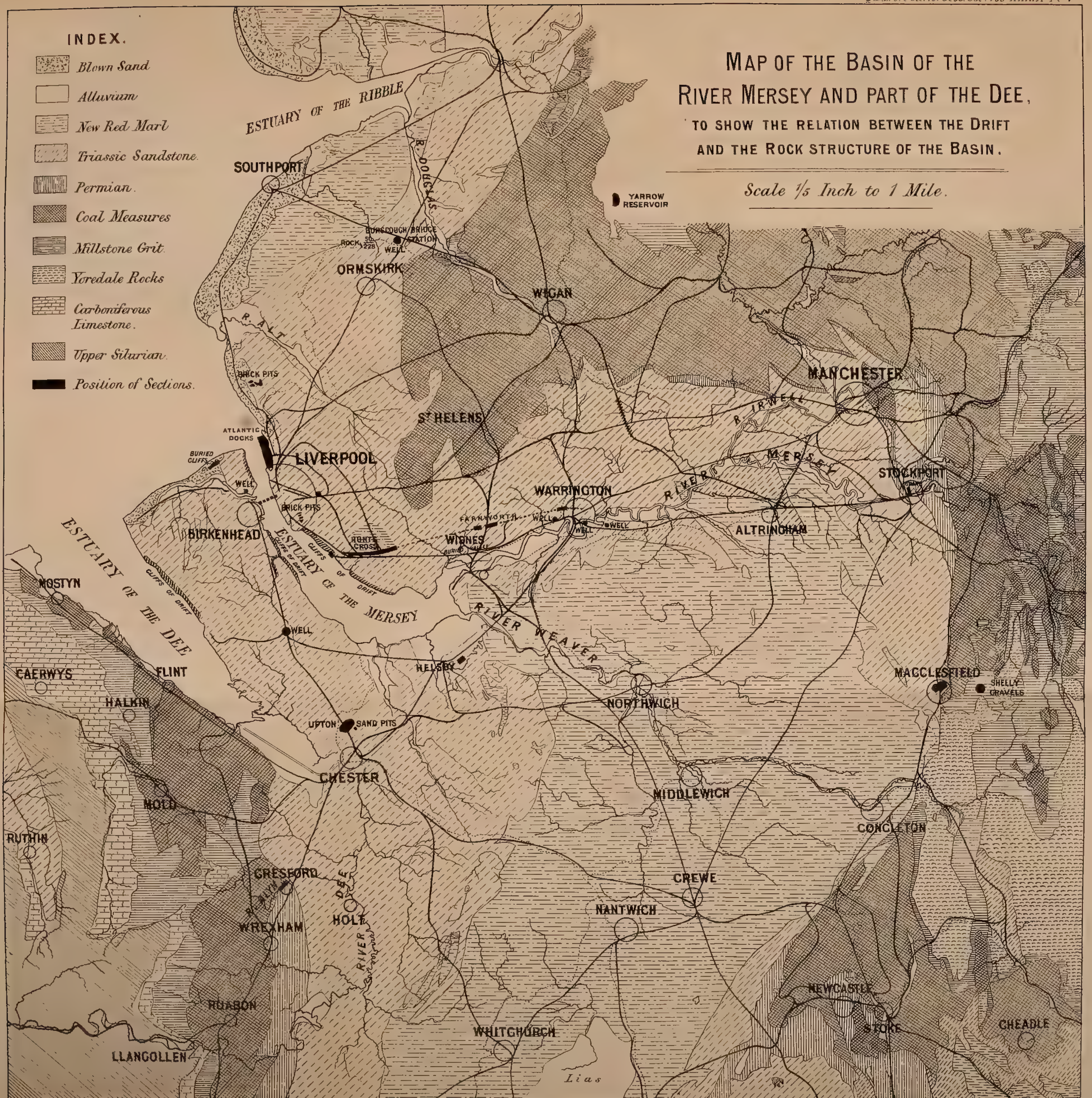


INDEX.

-  Blown Sand
-  Alluvium
-  New Red Marl
-  Triassic Sandstone
-  Permian
-  Coal Measures
-  Millstone Grit
-  Yoredale Rocks
-  Carboniferous Limestone
-  Upper Silurian
-  Position of Sections.

MAP OF THE BASIN OF THE  
RIVER MERSEY AND PART OF THE DEE,  
TO SHOW THE RELATION BETWEEN THE DRIFT  
AND THE ROCK STRUCTURE OF THE BASIN.

Scale  $\frac{1}{5}$  Inch to 1 Mile.







9. On GENERIC CHARACTERS in the ORDER SAUROPTERYGIA. By  
Prof. OWEN, C.B., F.R.S., F.G.S., &c. (Read December 20,  
1882.)

THE progress of knowledge of the species of Reptilia associated by De la Beche under the collective name Enaliosauria, led to the subdivision of that maritime group into the orders Ichthyopterygia and Sauropterygia\*, these terms being significative of their characters of resemblance respectively to Fishes and to Saurians.

Large accessions of species have since been made known in both orders. With regard to the first, I have not deemed the modifications in the dentition, in the shape and structure of the sternocoraco-scapular frame, in those of the fins, or the gradations of general bulk, sufficient, as satisfactory characters, for generic subdivision.

In the Sauropterygia, besides gradations of size, ranging, for example, from *Plesiosaurus Hawkinsii* to *Ples. Cramptoni*, there is a difference in the proportional length of the neck and number of its vertebræ relating to the size of the head it supports. In *Plesiosaurus homalospondylus*, for example, the cervical vertebræ are thirty-eight in number; in *Ples. rostratus* they are twenty-four. This character alone would not have obtained a generic separation: but a shortening of the neck, due not only to decreasing number but to altered proportions of the cervical vertebræ, when associated with a well-marked modification of the teeth, of the sternocoraco-scapular frame, and of the paddle-bones, called for a separation of the Sauropterygia into *Plesiosaurus* proper and a distinct genus, for which the name *Pliosaurus* was proposed†, indicative of the nearer approach which its species made to a generalized Saurian type.

In the Crocodilia, for example, a common character of the teeth is to have the usually simple conical crown, whether finely ridged or not, provided with a pair of enamel-ridges stronger than the rest, and placed on opposite sides of the crown.

In the genus *Plesiosaurus* the coronal ridges of the teeth are uniform or subequal, and the transverse section of the crown is circular or subcircular‡.

In the genus *Pliosaurus*, besides the shortness of the neck concomitant with hugeness of the head, a step towards the fresh-water Saurians is made by the presence of a pair of coronal ridges, longer and rather stronger than the rest, and rendered the more distinct by the characters of the parts of the tooth-crown so defined; the shorter enamel-ridges being limited to one division, and this portion moreover

\* Owen's 'Palæontology,' 8vo, 1860, pp. 198, 209.

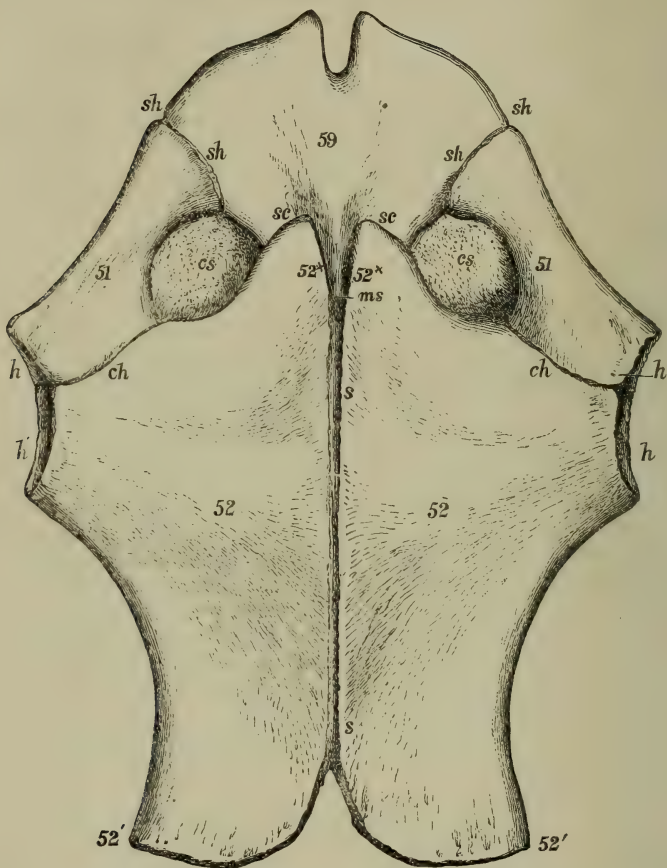
† "Report on British Fossil Reptilia," part ii. in 'Reports of the British Association for the Advancement of Science,' 1841.

‡ "Monograph on the Sauropterygia," volume of the Palæontographical Society, issued 1865, pl. ix. figs. 3-9.

being strongly convex; while the opposite portion is but slightly convex and is unridged. A single tooth, like some other fossilizable parts, serves unequivocally to indicate its belonging to a Pliosaur\*.

I will not dwell on the distinctive characters manifested by the fin-skeleton†, but proceed to detail those shown by the sterno-

Fig. 1.—Diagram of *Sterno-coraco-scapular mass* in *Plesiosaurus*.



coraco-scapular frame, premising a more detailed description of the characters of that part of the skeleton of *Plesiosaurus* than has elsewhere, so far as I can find, been given.

In Sauropterygia the place and function of a sternum are mainly supplied by the pair of coracoids (figs. 1 & 2, 52) which meet and

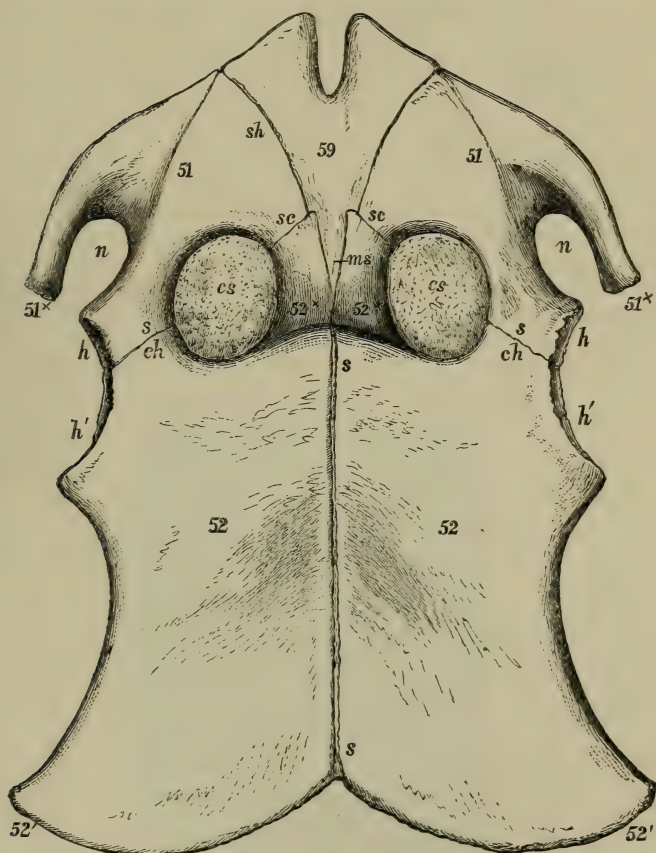
\* Id. ib. issued 1861, pl. vii., and 1862, pl. xii.

† Id. ib. issued 1862, pp. 9-11, pl. iv.



join by a longitudinally extended suture (*ib. ib.*, *s, s*) below the thoracic part of the abdominal cavity. Posteriorly to ('sacrad of') this mesial suture, the coracoids diverge and terminate freely by a broad margin, each with an angle (*ib. ib. 52*) inclining "laterad." Anteriorly ("atlantally") the sutural portions slightly diverge (*ib.*

Fig. 2.—Diagram of Sterno-coraco-scapular mass in Pliosaurus.



*ib.* 52') and expose the hinder ("sacral") end (*ib.* *ib.*, *ms*) of the mesial plate, 59, representing an episternum. Laterally, each coracoid contracts in length, becomes thickened, and presents two syndesmotie or roughened articular surfaces: the hinder one (*ib.* *ib.* *h'*) contributes the corresponding portion of the articular cavity for the humerus, the fore one joins the scapula (*ib.* *ib.*, 51) by the suture, *ch*, laterad of which the scapula contributes the fore portion, *h*, of

the glenoid cavity. In *Plesiosaurus* the hinder end of the scapula, which is the thickest part of the bone, is thus divided pretty equally between its coracoidal (*ch*) and humeral (*h*) articular surfaces, both being rough or "syndesmosal." In advance of the surfaces *h*, *ch*, the scapula thins and contracts, chiefly by a strong margino-mesial concavity, contributing the outer border of the "coraco-scapular vacuity" (*ib. ib.*, *cs*). The outer or lateral and thicker border of the scapula is nearly straight; and the bone extending forward and slightly mesiad, expands to unite with the episternum, *59*, by the suture, *sh*.

The episternum, *59*, presents anteriorly a mesial notch, from each angle of which the bone extends outward and backward to its sutural union, *sh*, with the fore end of the scapula. At this union the episternum contracts, and is continued backward to join the coracoids, passing a short way internal to ("centrad" of) them, and appearing outwardly as a terminally pointed portion, *ms*, at the fore part of the narrow mesial interspace of the coracoids, *52\**, which interspace interrupts anteriorly their extensive mesial suture with each other.

Thus the sterno-coraco-scapular frame, or mass, presents an anterior and a posterior emargination and a pair of subcircular vacuities. The above-defined characters of this portion of the skeleton, save that of the scapular element, are common moreover to both the generic groups of the Sauropterygia.

The chief and suggestive modification of the mass in the Pliosaurian genus is the retention of a typical character of the scapula which is lost in the more modified or specialized Plesiosaurian forms, viz. the production of the part of the blade-bone (fig. 2, *51\**), laterad and dorsad, where it terminates freely †. This portion represents the main body of the scapula in the higher Vertebrates, but, as in the "Allantoic group" (Reptilia and Aves) ‡, without expanding.

The portion of the scapula, *51*, common to both genera, which contributes its share (figs. 1 & 2, *h*) to the glenoid cavity, is separated in *Pliosaurus* from the free portion, *51\**, by the notch, *n*. In advance of this the Pliosaurian differs from the Plesiosaurian scapula by its greater relative breadth, extending its sutural border, *sh*, mesiad, so as to touch or join the fore end of the coracoid, *52\**.

The coracoids retain their large proportional size, but have a less even or flattened outer surface; mesially they bulge to their common suture, *s*, giving more room to the ventral or visceral cavity; and, at the transverse margin parallel with the hind border which they contribute to the vacuities, *cs*, *cs*, they bend dorsad, suddenly contract,

† This character I added to the generalized illustration of the Sauropterygian skeleton in my 'Palæontology,' p. 227, fig. 71.

‡ "In their generation and development modern Batrachians differ from other cold-blooded air-breathers and agree with fishes. Birds, by genetic and developmental characters, as well as by the general plan of their organization, are more intimately and naturally allied to the oviparous Saurians than to the viviparous Mammals."—*Anat. of Vertebrates*, vol. i. 1866, pp. 6 and 7.

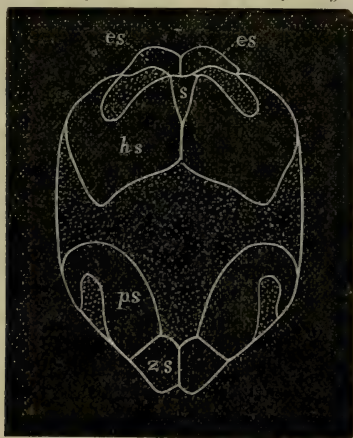
52', but contribute, as in *Plesiosaurus*, the mesial border of those vacuities, and articulate, underlapping it, with the hinder end of the episternum, 59. The proportional characters of this element are given in figs. 1 & 2.

In thus determining the homologies of the constituents of the complex bony buckler in Sauropterygia, I have exhausted every subject of comparison at my command, derivable from fossil remains of the group and from other Reptilian forms both fossil and recent, and in the latter have had recourse to modes and stages of development of the constituents of the answerable part of the frame.

The degree in which the abdominal surface is defended by bone in Sauropterygia resembles that in Chelonia. But the homology of the defensive parts can be safely predicated of but a small proportion only of the elements of the plastron. The episternum (figs. 1 & 2, 59) may answer to three of the Chelonian elements, viz. to the pair of bones so named, and marked *es* in fig. 3, and to the mesial piece, *s*, continued backward in a pointed form, and called "entosternum." But such constituents have coalesced into one bone in Sauropterygia, and I have no evidence, as in Chelonia \*, of its development from several centres.

One might be tempted by the size and shape of the parial elements of the plastron, *hs* (hyosternals), in the immature tortoise (fig. 3),

Fig. 3.—Development of Plastron, young Tortoise.



to regard the broad coracoids, 52, in figs. 1 & 2, as homologues, especially in the Chelonian half-developed state, when the fore and outer angle is produced in direction and degree like the scapular process, 51\*, in *Plesiosaurus*. But the process in the plastron of the Tortoise expands as it grows, and ultimately articulates with the dermo-marginal pieces of the carapace; it is, like them, a "dermal

\* "On the Development and Homologies of the Carapace and Plastron of the Chelonia" (Philosophical Transactions, 1849).

bone." The true homology of the constituents of the sterno-coraco-scapular frame is yielded by the endo-skeleton of *Chelonia*, in which the true coracoid is the largest and broadest of the elements of the shoulder-arch, the mesial margins almost meeting beneath the fore part of the thoracic-abdominal cavity.

Recalling the impression made on the mind of Cuvier\* by the first account of the *Plesiosaurus dolichodeirus*, we can appreciate the advantage and reward of continued researches, in the blotting-out of seeming anomalies, and in the addition of features of affinity linking on the strange extinct form (brought to light by Conybeare) to the general Reptilian type, and diminishing the intervals which seemed to exist in the series.

The few and short cervical vertebræ in *Pliosaurus* manifest, with these Ichthyosaurian proportions, by their amphicælian, almost flattened, articular surfaces, characters of contemporary Crocodilia, of which Reptiles we are also reminded by the short and thick neck, the large head, and the powerful jaws of the later-found Sauropterygian genus. The teeth, moreover, are now implanted in distinct sockets; and the blade-bone resumes its normal character.

It is interesting to note that the species tending to diminish the interval that seemed to separate Conybeare's *Plesiosaurus* from the typical Reptilia have been hitherto obtained from Mesozoic deposits less ancient than the Lias. All my evidences of *Pliosaurus* have been derived from Kimmeridgian and Portlandian beds.

A third generic modification of the Sauropterygia is indicated by teeth and a portion of the skull from a part of the Cretaceous series; but I wait for further acquisition of its remains before submitting to the Society the differential characters of the genus *Polyptychodon*.

#### DISCUSSION.

The PRESIDENT stated that great differences of opinion existed as to the form of the scapular arch in *Plesiosaurus*. He himself believed that there is evidence that in *Pliosaurus* there was a dorsal prolongation of the scapula similar to that found in the higher vertebrates.

\* "C'est par cet habitant de l'ancien monde, peut-être le plus hétéroclite, et celui de tous qui paroît le plus mériter le nom de monstre, que je terminerai cette histoire des animaux perdus."—*Ossem. Foss.* tom. v. pt. 2, p. 476, 1824.



10. *On the ELASTICITY and STRENGTH-CONSTANTS of JAPANESE ROCKS.*

By THOMAS GRAY, Esq., B.Sc., F.R.S.E., and Prof. JOHN MILNE, F.G.S. (Read November 2, 1881.)

(Abridged.)

THIS paper contains a description of experiments made for the purpose of determining the different moduli of elasticity, and the strength against rupture and crushing of some of the more common Japanese rocks. One main object of the experiments was to obtain data for the calculation of the theoretical velocity of propagation of earthquake-waves, and by comparison of this velocity with the results of observation, to gain some idea of the degree of continuity in the strata.

The experiments on the moduli and the rupturing strength were performed on round columns of the rock about 4 centimetres in diameter and 60 centimetres long; those on strength against crushing were for the most part made on round columns 4 centimetres in diameter and 12 centimetres long.

The Young's modulus of elasticity was calculated from the results of experiments on cross bending, the columns being supported at both ends.

The modulus of rigidity was calculated from the results of experiments on the torsion produced by the application of measured twisting motives.

The bulk-modulus was calculated from the known relation between it and the Young's and rigidity-moduli.

The modulus of rupture was found by observing the load required to rupture the column by cross bending.

The experiments on crushing were performed by means of a Bramah's press, the pressure being estimated by means of a Bourdon's gauge.

The following Table (p. 140) gives the results of the experiments; the headings of the different columns sufficiently explain their contents.

## DISCUSSION.

Rev. E. HILL thought that the results obtained might have another application. In studying faults and joints, the elasticity and capability of resisting crushing of different rocks must necessarily often be taken into consideration; and for such a purpose the determinations made by the authors might be of great service.

Kind of Rock.	Young's modulus in grammes per square centimetre.	Rigidity-modulus in grammes per square centimetre.	Length of the Young's modulus in centimetres.	Length of the rigidity-modulus in centimetres.	Calculated velocity of normal wave in centimetres per second.	Calculated velocity of transverse wave in centimetres per second.	Ratio of velocity of normal to velocity of transverse wave.	Modulus of rupture in grammes per square centimetre.	Maximum deflection before rupture in centimetres.	Modulus of crushing in grammes per square centimetre.	Length modulus of crushing in centimetres.	Density of rock.
Granite .....	$416 \times 10^6$	$128 \times 10^6$	$159 \times 10^6$	$48.9 \times 10^6$	$395 \times 10^3$	$219 \times 10^3$	1.80	$171 \times 10^3$	.070	$230 \times 10^3$	$87.4 \times 10^3$	2.63
Marble .....	$400 \times 10^6$	$119 \times 10^6$	$148 \times 10^6$	$44.1 \times 10^6$	$381 \times 10^3$	$208 \times 10^3$	1.83	$137 \times 10^3$	.075	$190 \times 10^3$	$70.4 \times 10^3$	2.70
Tuff .....	$189 \times 10^6$	$102 \times 10^6$	$82.9 \times 10^6$	$44.7 \times 10^6$	$285 \times 10^3$	$209 \times 10^3$	1.36	$131 \times 10^3$	.079	$114 \times 10^3$	$50.0 \times 10^3$	2.28
Clay Rock ...	$329 \times 10^6$	$177 \times 10^6$	$123 \times 10^6$	$66.0 \times 10^6$	$348 \times 10^3$	$254 \times 10^3$	1.37	$252 \times 10^3$	.069	$154 \times 10^3$	$57.5 \times 10^3$	2.68
Slate .....	$686 \times 10^6$	$229 \times 10^6$	$250 \times 10^6$	$83.6 \times 10^6$	$451 \times 10^3$	$286 \times 10^3$	1.58	$417 \times 10^3$	.079	$313 \times 10^3$	$114 \times 10^3$	2.74

11. *On the METAMORPHIC and overlying ROCKS in parts of Ross and INVERNESS SHIRES.* By HENRY HICKS, M.D., F.G.S. *With Notes on the Microscopic Structure of some of the Rocks by Professor T. G. BONNEY, M.A., F.R.S., Sec.G.S.* (Read February 7, 1883.)

## (PLATE VI.)

## Contents.

1. Introduction.
2. Upper part of Glen Logan.
3. Neighbourhood of Achnasheen.
4. Ben Eay and Loch Clare to Glen Carron.
5. Achnashellach, Loch Doule and Strathcarron.
6. Loch Kisborn to Loch Carron.
7. Attadale, Loch Carron.
8. Strome Ferry and Loch-Alsh Promontory.
9. Loch Shiel to Caledonian Canal.
10. Conclusions.

1. *Introduction.*

SINCE I communicated my paper to the Geological Society in 1878, on the rocks in the neighbourhood of Loch Maree, Ross-shire, I have revisited the north-west Highlands on two occasions, viz. in the spring of 1880, and in the spring of last year. During these visits I devoted my time to the examination, in various areas, of sections which seemed likely to furnish evidence confirmatory or otherwise of the views which I had ventured to lay before the Society. In this paper I propose to give the general results obtained from these examinations, and to treat more fully those sections which appear to offer any conclusive evidence. In each of the areas examined I made large collections of rock-specimens; and numerous thin sections for examination with the microscope have been made from these rocks, and submitted for special examination to Prof. T. G. Bonney, and Mr. T. Davies. The former has kindly furnished the notes on these sections which are appended to this paper; and to both, on this as on so many former occasions, I am indebted for most valuable assistance in the petrological work. The notes by Mr. Davies in the paper I published in the Geological Magazine in 1880, on the Gairloch and Ben Fyn districts, have also so important a bearing on the questions discussed in this paper that I shall find it necessary to refer frequently to them.

The notes in that paper on the Gairloch specimens are particularly important, as they prove clearly the presence in that western area of rocks which cannot be differentiated from many rocks in the eastern area of Ben Fyn, included by Murchison, Geikie, and others in the so-called newer gneiss of Silurian age. This group of Ben Fyn is in this paper taken as the type to which is referred the newer series of metamorphic rocks of Pre-Cambrian age in these areas as distinguished from an older, or Loch-Shiel series, and the supposed still older Loch-Maree series.

In a former paper\* I placed the axis of the oldest rocks in the direction of Loch Maree, with newer beds to the south west at Gairloch and to the north-east about Ben Fyn. In doing this I did not necessarily mean to correlate the series at Gairloch with those of Ben Fyn, but believed them to be so closely allied that they could be easily included in one great group. The more hornblendic varieties along the shores of Loch Maree and the granitoid rocks south of Poolewe were, in my opinion, of older types; but whether separated from the former by actual unconformity or not I was unable to say.

Without referring again to the several views maintained in regard to the metamorphic rocks in the eastern areas, with which I have chiefly to deal, it is clear, as specially bearing upon those views, that the following points have to be kept constantly in mind in these inquiries. (1) Is the stratigraphical evidence as to a continuous upward succession, maintained by Murchison and Geikie, of that conclusive character that it must overthrow all petrological evidence which may seem to render this, if not impossible, yet highly improbable?

(2) Has this upward succession from Torridon Sandstone through the quartzite and limestone series anywhere been observed to graduate into gneiss rocks of the type such as we classify under the name Ben-Fyn series.

(3) Are not the flaggy micaceous rocks, such as those which we have described from the east side of Glen Logan, which probably overlie the limestone series (though there undoubtedly separated from the latter by a fault), more intimately allied in their microscopical and general characters to the Torridon series than to those of the Ben-Fyn type, which they are supposed to immediately underlie?

(4) Are there evidences of the disturbance of the strata by faults and inversions along these lines of such a kind as would be likely to greatly interfere with and to complicate the order of succession?

(5) Do the eastern metamorphic rocks show at different horizons and places that variability in the amount of alteration which is usually noticed in rocks subjected to local influences only? or do they not rather everywhere show an identical state of alteration, as if the result of some wide-spread cause, rather than due to local mechanical disturbances?

Before proceeding to describe the various sections examined since my paper was read in 1878, I may here take the opportunity of referring to a point in connexion with the section published in that paper which needs some explanation (though I have to a certain extent done so in my paper in the *Geological Magazine*, 1880). In that section the beds were accidentally placed at too high an angle in the part east of Glen Logan, and the floor made to appear to continue too uninterruptedly eastward. The published section, however, as mentioned in the discussion, was intended merely as a diagram; the views that I entertained were fully explained in the text†. Yet as it might tend to give a misleading idea as to the condition of the floor at this part, I think this explanation necessary. The presence

\* *Geol. Mag.* Dec. ii. vol. vii. 1880.

† *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 816.



of the floor in the entrance of Glen Docherty, as nearly as possible in the position indicated in that section, I clearly recognized again during my last visit. It is also seen as we leave the upper end of the glen; but between these points the ground has been so much broken up by faults passing along the glen and at right angles to it, that it is impossible to trace it continuously. The presence of the old floor in Glen Logan as far as the entrance into Glen Docherty (shown also in Prof. Bonney's diagrams and recognized clearly by him \*, and referred to also by Mr. Hudleston in his paper in the Proceedings of the Geologists' Association, 1879) is a fact of so much importance in these inquiries, in consequence of its being found eastward of the quartzite and limestone series, that the question of its presence in Glen Docherty may be almost dispensed with in the discussion. If the oldest rocks can be seen to rise up anywhere eastward of the limestone series, then the probability of the eastern true metamorphic rocks being parts also of the old floor, as maintained in my former papers, is rendered still stronger, especially if, as I hope to show in this paper, there is abundant evidence tending towards that conclusion.

I may here also refer briefly to the prevailing faults found in these areas. There can be no doubt, as shown by the directions of the lochs and valleys, that the main faults trend from N.E. to S.W. and from N.W. to S.E. Branching off from these, however, are many minor faults; but though these are continually met with, they do not usually greatly interfere with the succession, though they occasionally cut off considerable thicknesses of strata. Comparatively a few only of the faults are indicated on the map (Pl.VI.), and those mainly which have a bearing on the questions considered.

Some of the local names are taken from the recently published Ordnance map; but the majority are from that published by Black, as they agree with those used in my former paper. At that time the one-inch Ordnance map of these areas had not been published. The numbers on the map refer to the positions of the rock-specimens described, and correspond with the notes by Prof. Bonney.

All the rocks described are from points not referred to in my former papers, and they include all the varieties which appeared at all typical in the traverses made. One section only was examined to the north of the area previously described, the others being all to the south and east. The one to the north may be looked upon as a continuation to the N.E. of the former Glen-Logan sections.

## 2. *Glen Logan (or Laggan), Upper part.*

The gneiss, note no. 1, has a well-marked strike from N.W. to S.E., and in its general appearance seems typical of the older or what we call the Loch-Maree series.

About the cottages near the entrance to the glen on the west side leading to Loch Nafatt are exhibited well-rounded surfaces, upon

\* Quart. Journ. Geol. Soc. vol. xxxvi. p. 93.

which the strike of the foliation is beautifully shown: here the gneiss is seen at a height of from 300 to 400 feet above the datum-line; but it can be traced to a considerably greater height. A fault seems to extend along the glen above referred to; and the ground is broken up about the entrance. Though the rocks beyond this fault to the N.E. of the glen appear to differ in some important particulars from those described on the south side, it is clear, from the notes 2, 3, and 4, that they are also a highly metamorphic series. The fault has probably cut out a considerable thickness of the strata, being, as it is, nearly parallel with the bedding; therefore there is a rather abrupt passage from the one group to the other. On the south side of the glen, as already stated, the rocks are of the Loch-Maree type; but those to the north agree better in their petrological and physical characters with those of the Ben-Fyn type. I traced the section along the north side as far as Leckie, and found the beds to dip generally at a high angle to the north-east. In some places they are slightly contorted, but are seen quite evenly bedded and in regular succession in the gorge, where the bridge crosses the branch of the river flowing from a glen to join the main stream below Leckie. In the face of the hill on the south side of the main stream of the river and of the valley the beds dip to the S.E. These are much less altered than those described from the north side, and are evidently to be correlated with the flaggy micaceous series in the valley of Glen Docherty to the south. They compose the main portion of the mountain called Craig Roy. At one point they may be seen slightly bent towards the north-east, as if dragged down towards the fault extending along this valley towards Loch Fannich; but as they are entirely discordant in strike to those on the north side, and dip at a lower angle, it is clear that they are a much newer series, and in their petrological characters may be classed with the flaggy beds which are supposed to be seen in so many areas resting upon the limestone series. After a careful examination of the beds along Glen Logan and its branches, I came to the conclusion that these flaggy beds rest unconformably upon the Loch-Maree and Ben-Fyn series. The faulting has not, in my opinion, been of a character which would so completely baffle the order of succession here as to make this an illusory appearance only; and the result of the faulting can be calculated without much difficulty. As these beds of Craig Roy approach the western shoulder of Ben Fyn, they appear to dip slightly towards that mountain; but this also is evidently the result of a fault; for immediately we pass this point eastward, an entirely distinct group of rocks, with a strike from N.W. to S.E., at a very high angle, is met with; and the beds continue to retain this high dip, with here and there a fold over, through the whole range of mountains east of this point and to the north of Achnasheen.

### 3. *Neighbourhood of Achnasheen.*

The characteristic gneisses and mica-schists found in these mountains have been described in my former papers, and in that by

Prof. Bonney\*. They include coarse and fine-grained granitoid gneisses containing garnets and sphene, a well-marked augen-gneiss, dull-coloured and bright silvery mica-schists containing abundance of garnets, and micaceous gneisses with bands of white and black mica, with a moderate amount of quartz, felspar, &c.

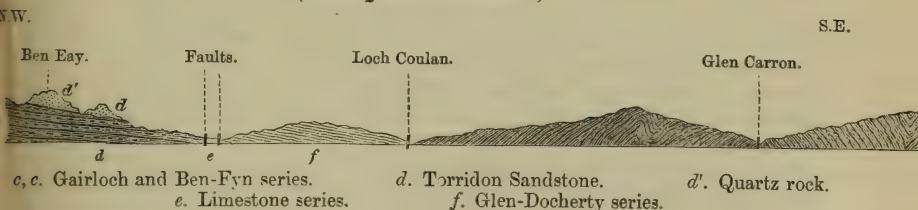
On the south side of Loch Roshk the same characteristic gneisses and mica-schists appear, and with a similar strike.

No. 5 is typical of the series in the shoulder of the hill between the east end of Loch Roshk and the valley to the south towards Glen Carron, which the Dingwall and Skye Railway traverses. To the east of the railway the rocks are also highly typical of the Ben-Fyn series. They lie at a high angle with an easterly dip. Here and there contortions are recognizable; but the only very definite change in the dip observed was in the mountains south of Loch Luichart†. In this area, as in the Ben-Fyn group of mountains, the degree of alteration is equal throughout from the base of the series to the top; and that the metamorphism cannot be due to any local mechanical disturbance is perfectly clear from the evenly bedded character of the majority of the rocks. In every specimen examined an intimately crystalline condition was observable, such as is usually considered characteristic of the true gneisses and schists; and generally also the minerals sphene and garnet, which could not have been originally present in the sediments, occur in abundance throughout the rocks.

#### 4. Ben Eay and Loch Clare to Glen Carron (fig. 1).

This section is taken in a line nearly due south of one described in my previous paper. It illustrates the general order of succession to the south of Loch Maree, whilst the former indicated the

Fig. 1.—Section from Ben Eay by Lochs Clare and Coulan to the S.E. of Glen Carron.  
(Scale  $\frac{1}{2}$  inch to 1 mile.)



order on the north side. As previously mentioned, the fault along Loch Maree has thrown down the floor and the overlying beds on the south side to a much lower level; and in consequence the old floor is lost further westward than on the north side. The diffi-

\* Quart. Journ. Geol. Soc. vol. xxxvi. p. 93.

† It is also mentioned by Murchison as occurring in Ben Eigen



culty of tracing the floor in the area now to be described is also greatly increased in consequence of the very highly faulted condition of much of the ground. If we begin the section with Ben Eay, we shall find that the Torridon Sandstone, which forms the base of this picturesque mountain, rests towards the north-west on a floor of the old gneiss, but at a much lower horizon than it does at Ben Slioch on the north side of the lake.

The Torridon Sandstone in both cases is alike in its general characters. It is occasionally brecciated, though much less so than in the mountains still further west, about Gairloch. For the most part it shows well-rounded fragments along this line and as far as the shores of Loch Torridon. Here and there shaly bands are found; and on the north shore of Loch Torridon I found these occurring almost to the base of the series. The colour of the sandstone varies from a bright pinkish and reddish colour to a dark green. The former is due to the felspar present, and to a reddish coating of the quartz; and the latter to a fine chloritic material disseminated through the rock, and also coating the quartz grains. Indications are abundantly present in the sandstones and breccias of the kinds of rocks which must have yielded the materials; and it is abundantly clear that they must have differed considerably at the time in their degree of crystallization. For instance, at Gairloch the fragments may be readily matched with the rocks on the upturned edges of which they now repose. In the Torridon area the evidences are clear that similar rocks were being denuded, as well as some chloritic rocks and some less altered slaty beds. That fragments of these less altered rocks occur here in combination with those of the true gneiss rocks is clear proof that there were some Pre-Cambrian rocks in these areas, as in Wales, which had not undergone a great change before the Cambrian rocks were deposited upon them. These comparatively unaltered rocks in Wales have not, as shown by the fragments in the conglomerates, undergone much change since that time, though they have been depressed to great depths and have suffered repeated crushings and other effects of local disturbances. The finding in these areas, as in Wales, of fragments of highly crystalline rocks with those so much less altered is most interesting, and should lead us to be careful in placing any of the even moderately altered rocks in the newer series, unless the evidence of their geological position is beyond the possibility of doubt.

We see therefore from the fragments in the conglomerates and sandstones in these areas that some comparatively but slightly altered rocks were being denuded by the Cambrian seas; hence we must be prepared to meet with these somewhere. Possibly this fact may have a more important bearing on the supposed evidence of progressive metamorphism in these areas than we are able at present to realize.

In this area there seems to be clear evidence that the quartzite series was deposited unconformably on the Torridon Sandstone. In the quartzite series are some subordinate bands of a yellowish calcareous shale. These are the so-called fucoidal bands, found here and



at many points north of this area. This series is well exposed capping Ben Eay and the other mountains towards Loch Torridon.

The dip is towards the east; but the series is only found in a very broken condition in the low ground towards Loch Clare. A portion only of the next or Limestone series also is exposed here, in consequence of the very faulted condition of the ground.

Were this section alone to be taken as showing the order of succession in this area, the evidence as to upward passage into the next series would be almost valueless, as the faults are amply sufficient to bring up the old floor to appear to rest upon the Limestone series; and the advocates of that view could have justly claimed that the comparatively unaltered condition of the next series would only tend to show that the beds were the newer Pre-Cambrian rocks, which yielded the comparatively unaltered fragments found in the conglomerate here and at Loch Torridon.

As there seems, however, much evidence tending to the belief that these beds, which belong to the Glen-Docherty series, do rest conformably on beds of the Limestone series further north, it will be better to take for granted here that these are newer beds, and that they are thrown down against the Limestone series. They are to be traced continuously from Glen Docherty to the shores of Loch Clare and Loch Coulan. They dip to the S.E. with a gentle inclination, and throughout are a flaggy micaceous group, in some places, however, almost a clay-slate; at other points fine-grained quartzose rocks may be found. Superficially they put on sometimes a more altered look than is seen either in the sandstones and clays of the Limestone series immediately below, or in the Quartzite and Torridon group; but on microscopical examination the fragmentary character of the series is always well marked, and after a very slight examination no one would be likely to be led to the mistake of associating them with the true gneisses and mica-schists of either the eastern or the western area. Beyond and to the north-east of Loch Coulan they are entirely cut off by a fault from the next rocks to be described. To the south also they are cut off from the Torridon-Sandstone and Quartzite mountains, which extend eastward at a greater elevation parallel with these supposed much newer rocks.

The presence of great mountains of Torridon Sandstone capped with quartzite to the south of Loch Clare and Loch Coulan, and extending as far as Loch Carron, proves beyond doubt that this region has suffered enormously from various kinds of disturbances. The faults, it is certain, must in this area have had a marked influence on the succession, since it is perfectly clear that the same rocks as those met with thrown down in the valley to the north-west of Loch Clare are found capping mountain after mountain far away to the south, whilst the uppermost flaggy beds may almost be said here to dip towards and even below them. That the Sandstone-and-Quartzite of this area is nothing more than the same series that was met with at Ben Eay and in the mountains south and west of that point, carried further eastward, there cannot be the shadow of a doubt to the mind of any one who thoroughly explores it; therefore

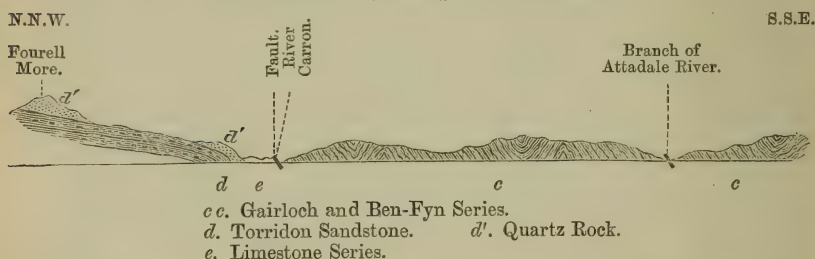
any supposition of their being higher beds of sandstones and quartzites reposing upon a lower quartzite-and-limestone series must be entirely cast aside. These rocks will be further referred to when describing the areas of Achnashellach and Strathcarron.

Continuing the section eastward of Loch Coulan, still in somewhat broken ground, we come upon a series of rocks entirely unlike those referred to as the Glen-Docherty series. As the road (private road belonging to Lord Wolverton) leading to Achnashellach crosses the ridge the mica-schists described in the Appendix, note no. 6, are found. The general dip is to the N.W.; but here they are considerably contorted, and a dip to the S.E. is soon afterwards recognized for a short distance in the same rocks. In descending towards Achnashellach the rocks no. 7 are met with, and apparently as belonging to the same series as the above, though the evidence of this is not quite certain. As we approach towards the station, undoubted old rocks of the type described under no. 9, and a reddish felspathic group not unlike the old rocks of the Logan valley, appear. On the roadside immediately to the west of the station, Torridon Sandstone is found faulted against this old rock.

### 5. *Achnashellach and Strathcarron* (fig. 2).

In the gorge of the river in the private grounds of Achnashellach Lodge an excellent section of the quartzite series is exposed. Towards Loch Doule the beds dip at an angle of about  $45^\circ$  to the S.E., evidently as the effect of the main fault in the Loch-Doule valley. A moderately high dip prevails also for a considerable distance up the valley leading to Loch Corry Lair, and the quartzite

Fig. 2.—*Section across the Carron Valley, between Loch Doule and Loch Carron.* (Scale  $\frac{1}{2}$  inch to 1 mile.)



series is seen as if resting almost conformably upon the Torridon Sandstone. The latter is passed over at the highest point between Achnashellach and Loch Corry Lair, and the succession is to be clearly made out in the mountains to the N. and S. of the pass. The mountains to the west of this lake also seem wholly made up of Torridon Sandstone capped with quartzite. That these are true Torridon Sandstones, and not subordinate bands in the quartzite series, is perfectly clear to any one who has seen the succession on the Torridon shores. The thickness also is very great, evidently several

thousands of feet. Conglomerates are seen alternating with the sandstones; and in these are found occasionally large fragments of greenish schistose rocks, very like some of the rocks found in the range of mountains to the north-east, supposed by Murchison and Geikie to be newer than these groups, but which I maintain belong to a much older series. How it can possibly be supposed that the rocks forming the mountain Cairn a Grubie to the N.E. of Achnashellach repose upon the quartzite series of this area, I am quite unable to make out. As already shown, the dip is in some cases in exactly the opposite direction; and even when it is reversed to the S.E., the strike would be directly against, and not over, the Torridon and Quartzite series. Altogether the evidence here is most decidedly opposed to any view of an upward succession into the gneissic and chloritic series. In travelling along the Loch-Carron road we meet with the quartzite as far as Coolagin. In the bed of a river coming down from the mountains on the N.W., just beyond this point, another clear section is exposed, and the uppermost beds of the quartzite series full of so-called Annelid-tubes are found. These are succeeded in the low ground towards the main river by the Limestone series. The limestone here is undoubtedly, from its general appearance, identical with that found in the western area about Kishorn, to be described further on, and seems in many respects closely allied to the Durness and Assynt limestone of the north. The position of the quartz rock, with Annelid-tubes, relatively to the limestone seems also to lend further weight to this supposition. The Torridon Sandstone is met with higher up the stream, and is seen there to underlie the quartzite series as in the Achnashellach valley. The succession is therefore, on the whole, more perfect also; for we meet with Torridon Sandstone to the N.W., and in descending towards the Loch-Carron valley the Quartzite series resting upon it, and afterwards the Limestone series in its proper position. These are thrown down together at a high angle towards the main fault in the Loch-Carron valley, and evidently immediately against the true gneiss rocks of the Ben-Fyn type which are found in the rising ground on the east side of the valley. The section, fig. 2, is intended to explain the succession along this line as far as the fault, and it is then carried across the mountains immediately to the west of Strathcarron Station, which consist entirely of rocks of the Ben-Fyn type, such as are described in the notes (Nos. 23-27) by Mr. Davies to a former paper\*, and of some allied rocks described by Prof. Bonney in the notes 18-21 in the Appendix to this paper, to be referred to further on in the description of the section in the Attadale valley.

#### 6. *Loch Kishorn to Loch Carron.*

In the area between these two lochs I examined several very interesting and important sections in connexion with some of the questions considered in this paper. I also ascended the highest

\* Geol. Mag. dec. 2, vol. vii. 1880.



mountain in the area, Glas Bheinn, to see whether the interpretation furnished by the lower ground was equally applicable to the highest points. To the north of this area we have the mountains of Torridon Sandstone, capped with quartzite, already referred to, and to the west the great mountains of Torridon Sandstone in the Applecross district. It seems to be bounded more or less by faults in all directions, and some of these must be faults of considerable magnitude. With the exception of the broken patch of the Limestone series on the shore and to the north of Loch Kishorn, I have indicated the whole as belonging to the Ben-Fyn series (or stage of crystallization); but this is to some extent only a provisional arrangement, as it is quite possible that a large proportion of the rocks in this area may prove to belong to a distinct group not represented in the Ben-Fyn district. That they are for the most part equally altered with that group there cannot, however, be any doubt; hence instead of classifying them under a new name, I have thought it best at present to associate them together. Sir R. Murchison has described the rocks in this area as being of Silurian age, the limestone of Loch Kishorn being at the base, with an ascending succession towards Loch Carron. In his joint paper with Prof. Geikie\* it is stated that the Kishorn limestone may possibly "be the same as that of Loch Carron, Loch Coulan, and Glen Cruchalie—that is, the limestone zone between the lower quartz-rock and the upper quartzose flaggy series; or, like the lower limestone of Ben Eay, it may be a local deposit occurring in the lower quartz-rock." It is also stated by them to be "underlain by white quartz rock, which, coalescing with that above the limestone, forms one series, below which lie the Cambrian sandstones swelling up into the great mountains of Applecross." Prof. Nicol says† that the "limestone rests on the quartzite, which in one place dips at  $15^{\circ}$ , to S.  $40^{\circ}$  E. The limestone is, as usual, more broken and irregular, but near the bridge to Applecross it dips at  $64^{\circ}$ , to E.  $8^{\circ}$  N. The talc-slates on the east have a dip of  $20^{\circ}$ , to E.  $30^{\circ}$  N.: and, on the whole, lower angles than those given in my former paper seem to prevail in these beds. Granulite and hornblende-rocks, however, abound near the line of junction; and I was still unsuccessful in finding any point where the talc- or mica-slates overlap the limestone or quartzite. I have now no doubt, from the facts seen at the junction in other places, that the limestone and talc-slate are divided by a line of fault. The occurrence of the limestone in this position, though quite analogous to what is seen in Assynt, is very important. It lies in a low valley at the foot of the red sandstone hills of Applecross, more than 2000 ft. high, and, as its regular position is above the quartzite, it must have been thrown down fully 3000 ft." After carefully examining the section at this point, I felt satisfied that the description given by Prof. Nicol was the correct one, that the Quartz-rock and Limestone series have been thrust in among the old rocks by faults, and that the evidence is altogether opposed to the view that they underlie in conformable order the highly metamorphic series to the east. I examined the latter

\* Quart. Journ. Geol. Soc. vol. xvii. p. 197.

† Ibid. p. 107.



at many points and found none that could be considered even partially typical of the Glen-Docherty series. The limestone of Loch Kishorn (note 32) is exactly like that which I have already described near Strathcarron. It is frequently brecciated and generally of a bluish or greyish colour. It is traversed also by cherty layers; and though fossils have not as yet been found in it, it seems altogether so like that in which fossils occur at Durness that I believe they may yet be discovered. The sandstones in association with the limestone are also so exactly like those found in other areas that they need not be referred to. They are in no part here more altered than are the ordinary fine-grained Torridon Sandstones of the typical areas. Besides the schists to the east of the limestone mentioned by Prof. Nicol, I found, in the gorge through which the road to Jeantown passes, a series of red augen-gneisses of rather a peculiar character, in association with greenish-looking hornblendic schists. A specimen of this augen-gneiss is described in note no. 12 by Prof. Bonney. In ascending the hill eastward from this point, hornblendic schists with red feldspathic lines and rather massive-looking rocks of a green colour freely permeated by epidotic veins are the prevailing types. At the crest of the hill and in descending to Jeantown, reddish quartzose and other gneisses more approaching the Ben-Fyn types are found, and the beds become on the whole thinner and more contorted, a distinct reversed dip being found to the south of Jeantown. Directly to the north of Jeantown, on the shore of Loch Carron, the dark micaceous schist (note no. 11) is met with. These schists and the quartzose gneisses are found extending along the shore to Loch Carron Kirk, from which point I ascended the mountain Glas Bheinn, and their dip is generally eastward.

In ascending Glas Bheinn until a height of about 600 feet is reached the usual Ben-Fyn types of gneisses are found; but beyond this, and reaching quite to the top of the mountain, the hornblendic gneisses described in note 11 are the prevailing types. Indeed the central portions of the mountain and its shoulder to the west seem chiefly to consist of these rocks. Numerous bands of a reddish feldspathic rock and segregation veins of felspar and quartz are also abundantly present in the series. The whole aspect of these rocks to the very top of the mountain calls to mind rather the older Hebridean series than the Gairloch or Ben-Fyn types. Yet as the latter seem to repose upon these on the east side they are for the present grouped together. The strike of the beds is usually from N.W. to S.E. or from that to N. and S.; and the dip, generally high, is in some places almost vertical.

The presence of a group of gneisses of so old-looking a character, and with a crystalline condition, as shown in microscopical sections, not to be distinguished from the oldest gneisses of the Loch-Maree type, reaching to the crest of a mountain of over 2300 feet in height in an area regarded as containing the so-called newer Silurian metamorphic rocks only, and east of the limestone series, is a fact of enormous importance, especially as we are told by Murchison and Geikie that the rocks found in this area are newer than the Lime-

stone series of Loch Kishorn, and that they repose conformably upon the latter. Not only does it seem incomprehensible from their peculiar mineral characters that these can be altered Silurian rocks, but the evidence afforded by the strike, which is directly opposed to that of the unaltered Torridon-Sandstone and Quartzite series forming the mountains directly to the north, and the fact, moreover, that here and there we meet with rocks in the latter area peculiarly like those of the Glas-Bheinn type peeping out from below the Torridon Sandstone, would seem to indicate that the conclusions which have been arrived at as to there being evidence of a continuous upward succession in this area are erroneous.

### 7. *Attadale, Loch Carron.*

In the Attadale valley, which runs in a direction nearly east and west from the east side of Loch Carron towards its upper end, an unusually good exposure of the gneiss rocks and mica-schists of the Ben-Fyn type may be examined.

In the railway-cutting (as we approach the railway station from Strathcarron) rather massive beds are exposed, dipping at an angle of about  $45^{\circ}$  to a little north of east. These gneisses contain a considerable amount of pinkish felspar in association with brown mica and quartz. Veins are occasionally found also traversing these beds. Between Strathcarron and this point the ends of the beds are frequently exposed, as if sharply cut off by the fault of the Loch-Carron valley, and deeper beds are found here than in the hills directly east of Strathcarron Station. In ascending the Attadale valley along the north side, the next series to be noticed, after those characteristic of the entrance, No. 18, are some dark mica-schists, No. 19. These are considerably contorted and are well exposed near a farm-house on the left-hand side of the road. The general dip here, though there are some minor folds, is still to the east.

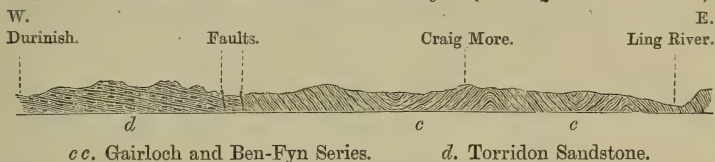
Beyond this point augen-gneisses identical with those found at Ben Fyn are met with; these are succeeded by dark grey gneisses and mica-schists, and towards the upper end of the valley by the more quartzose gneisses, Nos. 20 and 21. These last are evidently the same gneisses as those found so well exposed in the mountains directly to the east of the Strathcarron Station, where they are seen dipping at a high angle to the east. After traversing these mountains in various directions, I met with no rocks that could in any way be looked upon as otherwise than typical of a highly metamorphic series. Bed by bed they may be examined, and in sections showing thicknesses of several thousands of feet. An upward sequence is readily made out, and the several minor series show everywhere, as nearly as can be conceived possible, an identical state of alteration. After a time the observer cannot fail to realize in these areas that he is meeting continually with series having a very wide distribution, many of them also attaining to great thicknesses, but repeated here and there in great folds. The amount of contortion is not great, except in the more micaceous beds; and there is not apparently

any very marked difference in the crystalline condition where they are locally disturbed. The succession, as made out in these areas, would indicate that rocks of the Glas-Bheinn type (greenish hornblendic gneisses and pinkish felspathic gneisses) are the lowest; that the next are the greenish micaceous schists and the augen-gneisses with black mica; and that these are followed by the grey gneisses and silvery mica-schists and the very quartzose varieties found towards the upper end of the Attadale valley. East of the last-mentioned points the beds present a more decidedly reversed dip to the N.W., showing indications of a great synclinal fold.

#### 8. *Strome Ferry and Loch-Alsh Promontory* (fig. 3).

The rocks exposed along the east side of Loch Carron, in travelling from Attadale to Strome Ferry, may be grouped for some distance with those found towards the entrance of the Attadale valley. They are thrown somewhat back by the fault, but otherwise retain a similar strike to those further north. About midway between the two points the beds appear to be repeated in one or more folds. As

Fig. 3.—*Section in Loch-Alsh Promontory.* (Scale  $\frac{1}{2}$  inch to 1 mile.)



we approach Strome Ferry dark-green schistose rocks prevail. At and immediately to the south-west of Strome Ferry the rocks described under Nos. 13-17 may be said to be the chief types. Augen-gneisses and hornblendic schists, like those found between Jeantown and Kishorn, occur for some distance to the west of Strome Ferry, and may be examined on the shore. The hornblendic rocks are freely traversed by segregation-veins of pinkish felspar and quartz, and thin lines of a dull-coloured felspar are also frequently met with. These rocks have altogether an old look; but some of the thinner schistose rocks to the east do not show an equally crystalline condition, though evidently true schists. It is probable that a secondary change has taken place in some of these, and that their apparent want of crystallization is due to a kind of decomposition. The reddish augen-gneisses are found about a mile below Strome Ferry, on the road to Duncraig; but I was unable to trace them in travelling westward of that point. I believe that the floor is here dropped by a fault which seems to pass in a S.S.E. direction across the promontory; and this fault also tends to make the newer beds dip, as it were, towards and under the older rocks (see fig. 3). About this point also there are evidences of some minor faults.

Together these faults seem to have dropped the whole of the Limestone and nearly all of the Quartzite series; and the beds which are found west of this point should, I think, be grouped altogether



with the Torridon series. Mountains of considerable height appear to be completely made up of thick beds of sandstone interstratified with more flaggy beds. Nos. 28 and 29 may be looked upon as characteristic of those found in this area. On reaching the coast of Loch Alsh, near Balmacarra Hotel, reddish sandstones like No. 30 are found. The promontory west of the line of fault already mentioned consists therefore mainly of Torridon Sandstone, with little or no signs of important alteration, but with slaty and flaggy bands showing indications of cleavage as the result of pressure.

The rocks beyond the fault towards the upper end of Loch Alsh are almost identical in character with those that have been described as occurring about Strome Ferry. East of this point, along the shores of Loch Duich, gneisses of the Ben-Fyn type are found, and associated with these are some bands of highly crystalline limestone. These are separated, according to Murchison\*, by "talcose, actinolitic, and micaceous schists, often serpentinous like the limestones themselves; red felspar-porphry and syenite also occur in bosses, dykes, and veins." Though I was unable to visit the sections along the shores of Loch Duich, I feel satisfied from the descriptions that have been given of the rocks by Murchison and Geikie and by Prof. Nicol, and from an examination which I have made of the specimens deposited from these areas in the Geological Museum, Jermyn Street, that they must be older than the Torridon Sandstone.

They are much like specimens which I collected along the shores of Loch Eil, from rocks underlying sandstones which must, I believe, also belong either to the Torridon or Quartzite series. These Loch-Duich and Loch-Eil types are probably the newest rocks of the Ben-Fyn type found on both sides of the axis of the older rocks as shown in the map (Pl. VI.). The main object I had in view in my exploration in these areas was to endeavour to trace the actual conditions at those points where it had been supposed there was clear evidence of a gradual passage from unaltered fossiliferous rocks to those but partially changed, and afterwards from the latter to the highly crystalline schists found in the more central areas. I did not therefore think it necessary to examine many sections south of the point last described, as all who have written on those areas state clearly that metamorphic series only occur there; and the specimens I have examined, which have been collected from those areas, prove this very conclusively. The only other section therefore that I need refer to in this paper is one I examined carefully to see the connexion between the very highly crystalline series of the more central portions of this district and the apparently less highly altered rocks directly west of the Caledonian Canal and to the east of the axis. Several sections across, from the west coast to the line of the canal, have been carefully described by Murchison and Geikie, and in these sections they invariably show that the more crystalline rocks are found in a line from the neighbourhood of Loch Shiel (by Loch Quoich and Glen Shiel) to Loch Affrick; and to the N.N.E. I have recognized the same types also as far north as the neighbourhood of Loch Luichart.

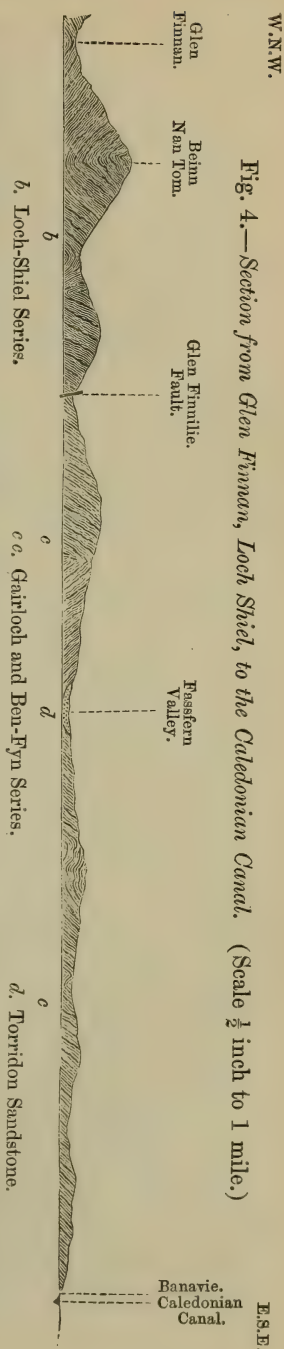
\* Quart. Journ. Geol. Soc. vol. xvii. p. 198.



9. *Loch Shiel to Caledonian Canal* (fig. 4).

In figure 4 I show the general arrangement of the rocks between Glen Finnan, at the head of Loch Shiel, along the north shore of Loch Eil to the Caledonian Canal. The more highly crystalline rocks are well seen in the mountains about and directly to the east of Glen Finnan, as well as along the roadside. I ascended one of these mountains, called Ben Nan Tom, and found it to be composed entirely of massive-looking gneisses, frequently hornblendic, and containing lenticular segregations and bands of hornblende, of a reddish and light-coloured felspar mixed with quartz, and of black mica. The hornblendic bands are described in note 22, and the gneisses from this point in note 23 of the Appendix. The rocks are beautifully contorted in places, and the strike in the foliation is from N.W. to S.E., or varying from that to N. and S. In many respects these rocks are much like those found between Poolewe and Gairloch, on the west coast; and it seems impossible to conceive that they can be, as suggested by Murchison and Geikie, only Silurian beds in an altered and crumpled condition. The interpretation as given by them occurs in the following passage:—"We have shown that the quartz-rocks and limestones of Sutherland range south-westwards through Ross-shire into the Isle of Skye,—that they are covered by a vast series of micaceous flaggy or gneissose schists; that these are disposed as a great synclinal trough, the centre of which traverses the head of Glen Shiel, the middle of Loch Quoich, and the watershed of Glen Finnan,—and that, by the curving of this trough, the quartzose beds which form its outer or lower edge along the western coast at Arisaig are brought up again along the line of the Great Glen"\*.

The highest beds are therefore placed by them at the point where we meet with the most highly altered rocks; and the least altered micaceous flaggy beds and the unaltered rocks are placed at the base of the trough to reach the surface along the line already described



\* Quart. Journ. Geol. Soc. vol. xvii. p. 207.

to the N.W. on the one hand and along the line of the Caledonian Canal on the other. Such a condition of things would seem peculiarly anomalous if true; but fortunately the evidence, when carefully examined, does not tend to bear out this strange interpretation, and a more natural one, and one more in accordance with recent views, is found to be the true one. Instead of a great synclinal with the most altered rocks held up by the less altered, the interpretation, as read by me, is that we have here a great, but much broken, anticlinal fold, and that these highly metamorphosed rocks formed an axis which threw off the newer beds on either side, or that these rocks are, if conformable with the series to the N.W. and S.E., the oldest rocks and at the base of the whole succession in this area. These older rocks also have been exposed by the denudation of the newer rocks, and the latter are dropped on either side by faults, in more or less broken synclinals.

There is ample evidence along the N.W. to show that the newer or Ben-Fyn series are repeated in broken folds, and that they dip as they approach the axis, frequently away from it. They do this clearly also as seen in the section on the S.E. side; but here the N.E. and S.W. fault has somewhat interfered with the order where they actually meet. In tracing the section eastward from Glen Finnan, rocks more nearly allied to the Gairloch and Ben-Fyn types (no. 24) are met with. In the line of Glen Fionn, at the head of Loch Eil, a granitic-looking rock is seen, not unlike that found in Glen Logan (the so-called Logan rock), and its association here with these old gneisses is interesting. Crossing the fault, which is a most marked one at this point, we come rather suddenly on newer-looking rocks, still a metamorphic series, but evidently of a newer type altogether than those found in the area between Glen Fionn and Glen Finnan. These are the rocks supposed by Murchison and Geikie to dip under the latter; but the evidence of a fault here is most marked, and, though the beds appear to dip towards the axis, the effect is clearly due to the fault. There is also some difference in the strike, as the newer rocks dip decidedly to the N.W. and afterwards to the S.E.

Grey micaceous gneisses, corrugated mica-schists, and strongly bedded quartzose gneisses are the prevailing types in this area. Near Fassfern rather thick sandstone-beds are found dipping at a very low angle to the S.E. These are clearly but little altered, and must, I think, be classed either with the quartzite series of the west or with the Torridon Sandstone. They repose upon the mica-schist series, and appear to have no direct relationship with the latter. They occur here in a faulted synclinal of the schistose series; so their actual position, whether as resting unconformably upon the schists or dropped amongst them by faults, is not quite clear. About Kilmallie the schistose series is again very well exposed, here dipping to the N.W. The rocks at this point consist of highly micaceous gneisses and mica-schists (no. 25), also some talcose and serpentinous schists. These are a truly metamorphic series, and cannot be differentiated from the Ben-Fyn types, but possibly should be classed with the newer portions of that series. The rock no. 26, evidently an

igneous one, is found on the Loch side of the road. The schists can be traced along the road towards Banavie; but before we reach the latter place a granitic-looking rock is met with, which, however, shows rather a gneissose appearance in places; this is described in the Appendix, note 27. It has an old look, and if not of a gneissose character, it must, I think, be an igneous rock of Pre-Cambrian age which has suffered a considerable amount of crushing and some change. In the area west of Glen Finnan, as along the lines of that district directly to the N., the gneisses and schists are of the true Ben-Fyn type. A collection of these may be examined in the museum in Jermyn Street. Other specimens in that museum show clearly that the old axis referred to above extends further south than the neighbourhood of Loch Shiel, and that rocks of the Glen-Finnan type are exposed at Strontian, almost directly to the south, in Argyleshire.

#### 10. *Conclusions.*

The facts derived from the careful examination of the various sections referred to in this paper do not appear to me to lend support in any way to the view propounded by Murchison and Geikie that the crystalline schists of their eastern areas repose conformably upon unaltered rocks containing Lower Silurian fossils. The supposed passage from unaltered to highly crystalline rocks has proved in each case, on examination, to be a deceptive appearance due either to a faulted junction or to some other accidental cause. The stratigraphical evidence therefore on the strength of which the whole theory depends for support fails entirely. To the east of Loch Maree it has been shown that the fossiliferous sandstones are succeeded by flaggy beds at a low angle, which dip away from them to the south-east. These flaggy rocks show, under the microscope, a slight amount of alteration; but the individual fragments out of which they have been built up are always easily recognizable, and there is no indication of that intimate crystallization of the felspar and quartz which is so characteristic of the true schists. The flaggy rocks meet the crystalline schists, which we recognize as belonging to the Ben-Fyn type, quite abruptly along a line to the east, and they are undoubtedly newer rocks than the latter. There is also generally a marked discordance in the strike of the two groups. At Achnashellach and Loch Doule, to the south of the lines last mentioned, the quartz rocks with Annelid-tubes abut against the same crystalline schists of the Ben-Fyn type, the limestone and flaggy series recognized in the other areas being entirely absent. Further south, however, near the head of Loch Carron, the limestone reposing on quartz rocks with Annelid-tubes in abundance is brought against the crystalline schists along its eastern margin by a fault.

The eastward dip which prevails in the unaltered rocks as well as in the schists along this area has led to the belief that there was here a conformable upward succession between the series. This appearance, however, has been entirely produced by the fault; and the apparent conformability does not prove to be any thing like so marked as has



been supposed, the strike in the crystalline schists being about due north and south, whilst in the unaltered rocks it is from north-east to south-west. At Loch Kishorn, much further to the west, the same limestone is thrust in among the schistose series by faults; whilst in the Loch-Alsh promontory the whole of the limestone and most of the quartz rocks have been cut off by faults, and beds belonging to the Torridon Sandstone series have been brought against and apparently made to dip under schists identical with those immediately in contact with the Loch-Kishorn limestone. The evidence therefore of great dislocations of the strata along these lines is most marked, and it is along these broken lines that the so-called gradual passage from unaltered to highly crystalline strata has been supposed to be seen. With the exception of the flat-bedded series found on either side of Glen Docherty there is scarcely any evidence whatever in these areas of the presence of rocks which can be classified as newer than the Limestone series. The least altered of those which are included in this paper in groups older than the Torridon Sandstone are more highly crystalline than are the majority of the Peibidian rocks of Wales, or of the Huronian rocks of Canada, each of these being undoubtedly of Archæan age. And by very far the largest proportion are equally crystalline with those found in the western series where overlain by Torridon Sandstone and also with the rocks characteristic of the groups found in the Hebrides. Were we also to exclude from consideration those which do not show an intimately crystalline condition, the chief conclusions arrived at would be still the same. There are clear indications in the so-called eastern as well as in the western area of several well-marked series in the schists. The main groups recognizable along the north-west coasts can be made out with equal clearness in the central areas. The same types are found to succeed one another; the same segregation-veins of hornblende, of quartz and pink felspar, and of black mica, and the same disseminated minerals which are in any way found to be characteristic of groups along the west coast are found equally abundantly in the schists of the so-called eastern areas. The most massive and most highly crystalline of the so-called eastern rocks are found towards the base of the series and in the most central portions of the area, and the more evenly bedded ones thrown off in broken folds towards the east and west. This interpretation, as explained in describing fig. 4, entirely reverses the order given by Sir R. Murchison and Prof. Geikie, who have maintained that the most highly crystalline rocks occur in a great synclinal trough supported by the fossiliferous quartzose series. The idea that the so-called eastern rocks retain a more regularly bedded appearance throughout than is usual in Archæan rocks is not borne out by examination. That a very regular stratification is well marked in a considerable proportion of these gneisses is perfectly true; but that the same may be said of a large proportion of the gneisses in the so-called western areas is equally true: similar evenly bedded gneisses, it is well known, are abundantly present also in the Laurentian rocks of Canada. Such a high state of crystallization as is found throughout in the evenly



bedded gneisses of the central areas of Ben Fyn, Mulart, &c. is itself one of the strongest arguments which can be adduced in proof of the high antiquity of these rocks. The advocates of progressive metamorphism in this region have strenuously maintained that so long as the beds retain their evenly bedded character foliation remains feeble, and that they only become highly metamorphosed when they undergo rapid plications and foldings. These rocks of Ben Fyn therefore should, according to that view, show but a partial change, whilst, as will be readily seen from the notes by Prof. Bonney and Mr. T. Davies, it is proved that they are in a highly crystalline condition. Other so-called eastern rocks, however, such as those referred to in the neighbourhood of Loch Shiel, are as greatly plicated as are any in the western areas. I have divided the Archæan rocks on the map into three groups, viz. the Loch-Maree, Loch-Shiel, and Ben-Fyn series; these may be unconformable to one another, though at present the evidence of this is not conclusive. A fourth group, less altered probably than any of these, and somewhat in the condition of the Peibidian rocks of Wales, may also possibly be partially represented in some of these areas, as some fragments which occur frequently in the Torridon sandstones and breccias are more nearly allied to such a group than to any of the others specially referred to in this paper. Fragments, however, which can be identified with rocks belonging to each of the groups mentioned are found in the conglomerates and breccias along the west coast; and these show clearly that little or no alteration has taken place in the crystalline condition of the underlying rocks since these fragments were derived from them. The whole of the evidence obtained from these examinations tends therefore to confirm the views maintained in my former paper, that the crystalline schists of these areas must all be of Pre-Cambrian age, and that they are not the equivalents of the fossiliferous Silurian rocks of the southern Highlands and of Wales.

## APPENDIX.

*Note on the LITHOLOGICAL CHARACTERS of a SERIES of SCOTCH ROCKS collected by Dr. H. HICKS, F.G.S. By Prof. T. G. BONNEY, M.A., F.R.S., Sec. G.S.*

IN the following remarks it is not my intention to attempt an exhaustive analysis of the microscopic characters of the rock-specimens which Dr. Hicks has been good enough to entrust to me for description. This seems to me hardly necessary after the full descriptions of rocks, in many respects similar, which have already been published by Mr. T. Davies\* and by myself†. Hence, in order to avoid burdening the pages of our Journal, I have, as far as possible, noticed in

\* Geol. Mag. dec. ii. vol. vii. pp. 103 &c.

† Quart. Journ. Geol. Soc. vol. xxxvi. p. 93.

detail only the points in which these specimens differed from those already familiar to me.

In examining these Highland rocks (and I might say others also) I have observed three rather well-marked types, indicating stages of metamorphism. In the first it is obvious that many of the constituents noticed in the slide, especially those of larger size, with most of, if not all, the felspar, are original. Still many of the quartz-grains present somewhat irregular peripheries, and appear clotted or agglutinated together, as in the most highly altered quartzites, instead of presenting the definite outlines of ordinary fragments; sometimes the smaller grains have even a chalcedonic aspect, as if of secondary origin. It is often doubtful whether the larger flakes of mica are endogenous or not, and it is quite certain that a minute flaky to fibrous mineral has been produced subsequently to the deposition of the rock. This is probably, in part at least, a hydrous potash- or soda-mica (very like that which has been recognized as sericite), and in part perhaps is nearer to actinolite. Epidote and occasionally small garnets of secondary origin are present. Of this stage of metamorphism the rocks forming the northern escarpment of the "Newer Gneiss," in the neighbourhood of the head of Loch Maree, furnish excellent examples.

In the second stage of metamorphism, while, when we regard the rock in the field, we can have no doubt of its sedimentary origin, bedding being often well marked and foliation distinct, yet, under the microscope, it is extremely difficult to identify any of the constituents, in their present condition, as of clastic origin. The quartz presents the appearances above described yet more markedly. One might have hoped to have recognized, as has been done in quartzites, original grains as nuclei; but in this I have not yet succeeded, though I have examined a fair number of specimens. The mica, garnets, &c. are almost certainly endogenous; and this appears also to be the case (though on this point I speak hesitatingly) with the felspar where present. Of this stage of metamorphism, which, so far as one can tell, is as complete as can be, the rocks of the southern face of Ben Fyn furnish excellent examples. In England I may cite as instances the schists of the Lizard peninsula, and a considerable number of those in Anglesey, though some which have been sent to me from that island belong rather to the former type.

Between these types intermediate instances will of course be found. The nature of the constituents and the mode in which the agents of metamorphism have operated must bring about varieties of results, and it would be extremely rash to attempt in every case a classification by microscopic evidence alone; cases there are and will be where "*noscitur a sociis*" will be true, and we must then decide mainly by evidence obtainable by field-work. I do not mean by this to say that the two methods of investigation will produce contradictory results, but that the microscopist, while certain that he has before him a distinctly metamorphic rock, will not venture to say to what extent alteration has taken place. I have

found myself in this difficulty with a few of the specimens described in this paper. They may be rather exceptional instances of the one or the other type, and with that conclusion I must leave Dr. Hicks to classify them. They will neither contradict nor confirm strongly any stratigraphical theory which he may have formed. The above difficulty may be partly due to the fact that in certain cases the Highland rocks have undergone great local crushing, I believe, always in the vicinity of faults. They thus present a fragmental structure; and it is by no means easy when some mineral changes have subsequently taken place to decide whether we are dealing with a rock of clastic origin, in the ordinary sense of the term, *i. e.* resulting from the denudation of one of the older gneisses, or with one of the latter, which has been crushed *in situ* and recemented. No doubt the point could in every case be settled by making a larger collection of specimens, or by having several slides cut from different parts of the same specimen; but I cannot venture always to decide it from the examination of a piece no bigger than a shilling, and it hardly seems worth while, where a crucial point is not involved, to go to considerable expense. Nowhere have I seen such numerous and marked instances of this local crushing as in the Highlands; but I have observed nothing to countenance Mr. Mallet's theory of vulcanicity.

It is by no means impossible that the apparently close resemblance occasionally observed between the above-named two groups of rocks may be due to the fact that the older has in many cases supplied the materials of the newer. Under these circumstances, if the latter had been exposed to much pressure and some chemical change, it would be by no means easy to separate the one from the other, even under the microscope. Now the Torridon sandstone and quartzite in the Loch-Maree region certainly derive the bulk of their materials from the old gneiss rocks described below as the third type; but the flaggy "newer gneisses," such as those in the escarpment near Loch Maree, seem to be made up of the *débris* from a schistose series, like that of Ben Fyn. For instance, the quartz in the older gneiss is very full of minute enclosures, many of them resembling irregular empty cavities, though occasionally very small bubbles may be detected, especially in the more minute and regular in form; so is that in the Torridon and quartzite (as a rule). The quartz in rocks of the Ben-Fyn type has comparatively few of these enclosures, so has that in the newest series. Mica also is common in the latter two, rarer in the former two rocks.

The third type, while agreeing with those described under the second head, as being metamorphosed to the highest degree, appears to differ in respects which can hardly be due to a mere prolongation of the metamorphic action. The bedding of these rocks is ill marked; they are coarsely crystalline and often granitoid in aspect, being then difficult to distinguish from rocks of igneous origin; and the same is true of their microscopic structures. In such cases, in the present stage of our knowledge (though I do not think it will be so always), we must be content to be sometimes uncertain whether we have



before us a granite or a gneiss. Examples of this class are the coarse gneisses of the Hebridean series, which underlie the Torridon Sandstone and many of the Malvernian rocks of England. At the same time it must be remembered that now and then beds more distinctly foliated also occur in this series.

Naturally we should expect that as a rule the above distinctions would have a certain chronological value, and thus we are justified in using them, in default of other evidence and with due caution, for purposes of classification. In the following notes I have, for convenience of reference, followed the numbering which Dr. Hicks had placed upon the specimens, but have added I., II., or III. according to the type of which the specimen reminded me, inserting a qualification where needed.

1 (Glen Logan). Principal minerals, quartz, felspar a good deal decomposed, but a considerable amount of plagioclase still discernible, generally extinguishing at small angles with the twin plane. In parts of the slide is a mineral which, at first sight, has exactly the aspect of grains of olivine in process of conversion into a greenish serpentinous mineral. Further examination, however, shows that the former mineral is garnet. The latter appears in part isotropic, in part shows filmy streaks of pale bluish light. I do not, however, observe here either the transverse microcrystalline structure of the "strings" or the opacite clotting so common in serpentine when formed from olivine. Granules of an earthy-looking mineral are probably formed by the aluminous constituent of the garnet, which, as these are not abundant, was probably Bredbergite rather than pyrope. So far as my experience goes, this replacement of garnet by a serpentinous mineral is very rare\* (III.).

2 (north side of Glen Logan, eastern branch). Quartz, mica (both white and brown, the latter partly altered into a green micaceous mineral), some felspar (rather decomposed), and a good many garnets almost colourless, but with many microlithic enclosures (II.).

3 (same locality). Generally similar, but with numerous small granules of a mineral which I take to be epidote.

4 (same locality). Macroscopically appears to be a compact gneissic rock; microscopically it exhibits a ground-mass, consisting mainly of quartz granules in which are scattered flakes of mica exhibiting a certain foliation, and grains, generally somewhat irregular in outline, of a rather decomposed felspar. The last look as if they might bear record of original constituents; but on the whole the rock appears to me to agree best with those in II. and to be more highly altered than is usual in I., the outlines of the quartz grains in the ground-mass being very irregular.

5 (south side of Loch Roshk). Macroscopically a not very fissile mica-schist; microscopically quartz, white and brown mica, with one or two small garnets; very typical example of II.

6 (top of hill-road to L. Coulan from Achnashellach). A rather fissile mica-schist, rich in a dark lead-coloured mica, very distinctly foliated. Two micas, both, I suspect, more or less hydrous, are present,

\* See Rosenbusch, 'Mikroskopische Physiographie,' vol. i. p. 163.



with a little chlorite in parts of the slide, a fair amount of epidote, and probably a little cyanite. Probably II.; but I think there has been some crushing which has given rise to difficulties.

7 (on side of hill, north of Achnashellach). A rather compressed micaceous schist, difficult to classify macroscopically. Microscopically it consists mainly of quartz granules and flakes of pale green mica like that often described, with epidote, a little felspar, iron-oxide, &c. There are certainly indications of an original fragmental structure, and the rock generally resembles No. I. series; but there has been a good deal of metamorphism.

8 (the same locality). The microscopic differences from the last one are only varietal.

9 (towards base of hill north of Achnashellach). A compact reddish and dull greenish gneissic rock, seemingly highly altered and even microporphyritic; but seen under the microscope a fragmental structure is at the first glance as conspicuous as in any of the No. I. series. At the same time, a more careful study gives rise to doubts as to whether this resemblance may not be illusory as regards its origin, and whether we have not here an instance of one of the older series locally crushed. At first I inclined to regard it as a member of the newer series; but repeated examination has produced considerable doubt on this point. Probably the question could be settled by cutting a series of slices from different parts of the block; but as I learn this is not a matter of great importance, I have thought the expense needless, and must leave the matter in uncertainty.

10 (shore of Loch Carron, north of Jeantown). A dark, rather heavy, moderately fissile mica-schist. Microscopically it exhibits brown mica in addition to that described above, contains little felspar, but some garnets, and appears to have undergone considerable compression at right angles to the planes of foliation. It has a good deal in common with the last three, but seems yet more highly altered. It reminds me much of a mica-schist which I have described and figured from the head of Glen Docherty.

11 (Glas Bheinn). This consists of a dull green hornblendic or chloritic mineral, parted by irregular cherty layers of variable thickness. The green mineral proves to be a well-crystallized hornblende, with characteristic cleavage. The cherty layers consist of grains of decomposed felspar crowded with micaceous films and granules of andalusite (?) and of quartz. The rock is much metamorphosed: but there has evidently been local crushing, infiltration, and secondary change to such an extent that it is difficult to say whether it is more typical of II. or III.

12 (valley between Jeantown and Kishorn, near Bridge). A handsome pale reddish augen-gneiss, the "eyes" being of felspar, and the ground-mass rather compact-looking. Macroscopically one would not hesitate to refer it to series II.; but microscopically the structure differs from what one expects: in a ground-mass of quartz and a very pale brown mica, together with a few felspar granules, occur irregular grains of felspar; the edges of these are, indeed, as it

were, fused with the ground-mass, and the granules of it one with another. Here, indeed, we seem to have a record of an original structure; and it is noteworthy that the felspar closely resembles that occurring, certainly in derivative fragments, in group I. Still I think the rock, on the whole, is nearer to II.\*

13 (a mile south of Strome, on road to Duncraig). Like 11, this has undergone so much crushing and recementation that it is difficult to come to a conclusion about it. The felspar is crowded with mica films and secondary minerals, some possibly fibrolite.

14 (shore of Loch Carron, south of Strome Ferry). A compact rather flaggy dull green and reddish schist, consisting microscopically of quartz and the usual mica with microliths of hornblende, and occasional larger grains of felspar and quartz. Structurally this rather resembles series I.; but the alteration is considerable, so that field evidence must decide whether it be grouped with it or with II.

15 (at Strome Ferry). A dull green slightly schistose rock rich in hornblende. Microscopically it consists of quartz and hornblende—the latter well cleaved, but irregular in external form, with a fair amount of sphene, a little felspar and numerous secondary microliths, aluminous and magnesian. On the whole I think this most resembles II.

16 (the same locality). A dull green slightly schistose rock, streaked with pale red and yellowish green. Microscopically it consists mainly of quartz, hornblende, and epidote, often rather impure. For mineral condition *cf.* No. 15. The rock has been crushed, which at any rate partly, perhaps wholly, accounts for its fragmental aspect.

17 (the same locality). A claret-red schistose rock, with little whitish specks. The general microscopic structure resembles No. 4; but there is less quartz, a good deal of ferrite, and considerable evidence of decomposition.

At Dr. Hicks's request I have paid particular attention to the structure of these rocks (13–17). They present similar difficulties to No. 12; but on the whole I think they group best with II., though here and there one seems able to identify original constituents more easily than is usual in this division.

18 (hill north of Attadale Station). A reddish, rather compact gneiss, poor in mica. Its microscopic structure is thoroughly characteristic of series II.; it contains two kinds of mica (neither abundant), a very few garnets, and a little epidote.

19 (north side of Attadale Valley, near Farm). Macroscopically and microscopically very like No. 10, but perhaps a little more altered, so that we may with more confidence group this with II. A little epidote is present.

20 (roadside, east of above). A moderately fine-grained gneiss,

\* Since writing the above, I have had the opportunity of examining another rock from this group, a rather compact-looking pinkish gneiss. Here, too, the rock, while macroscopically and, in some respects, microscopically, resembling series II., has certainly a fragmental aspect. Though the evidence is not decisive, I strongly incline to consider this aspect illusory and indicative only of subsequent crushing, and to refer both the rocks to the older series.

slightly porphyritic, of series II. ; almost identical with rocks I have described from Ben Fyn.

21 (towards upper end of Attadale Valley, north side). A finer, less micaceous gneiss ; but microscopically it has only varietal differences from No. 20, so II.

22 (Ben Nan Tom, head of Loch Shiel). A heavy black hornblende rock, with a parallel structure resembling one extremely metamorphosed. Under the microscope it exhibits numerous dark-green hornblende crystals, well cleaved and sometimes affording definite external faces ; with these are brown mica, sphene, and grains of quartz, and of a plagioclase feldspar, which has a rather large extinction-angle. The structure of this rock reminds me strongly (except that garnets are absent) of one described from Ben Fyn which was certainly intrusive ; and I cannot help suspecting it, notwithstanding its gneissic aspect, to be really a diorite.

23 (Ben Nan Tom). A handsome, rather coarse, pinkish and dull greenish gneiss. Consists of quartz, feldspar and dark mica, with a little epidote, apatite, and garnet. The mica is partly replaced by a dull-green chloritic mineral ; and between its cleavage-planes are occasional plates of a clear feldspathic mineral. The curious vermicular or micrographic structure often noted in highly altered gneisses is present in parts of the slide. I should unhesitatingly class this with III.

24 (Druim na Saille, head of Loch Eil). A fine-grained gneiss of the same type as 20, and, like it, a good example of II. ; contains sphene, epidote (?), and, I think, a little apatite.

25 (Kilmallie, Loch Eil). A brownish silvery mica-schist. Examined microscopically, it shows so much feldspar (rather decomposed) as to make the term gneiss more correct ; both brown and white mica are present ; the former a little altered. The micas are sometimes interlaminated, and the brown exhibits the inclusions noted in No. 23 ; some apatite is present. Decidedly II.

26 (shore of Loch Eil, west of Kilmallie). A rather compact dull green rock. Consists microscopically of a plagioclastic feldspar, with large extinction-angles, often much altered, and rather pale hornblende. There has been a little brown mica ; and there is a fair quantity of sphene. I have no doubt the rock is an igneous one, and, as I regard the hornblende as a secondary product, name it a hornblende-diabase.

27 (Banavie). A reddish feldspathic granitoid rock. Microscopically consists of quartz, feldspar (orthoclase, microcline, and a plagioclase), with a little rather decomposed brown mica. The structure is somewhat exceptional ; and I have had doubts whether this may not be a granitoid gneiss, but on a single slide, and without field-knowledge, will not venture to express a decided opinion.

28 (road to Duncraig, from Strone). A flaggy hard mudstone, looking little, if at all, metamorphosed. Under the microscope elastic quartz, feldspar, and mica are very distinct ; but there is a considerable quantity of very minute "sericite," which gives to the rock a microscopic foliation ; this implies a certain amount of meta-



morphism and may possibly suffice to enable us to group it with I. Its materials, however, are undoubtedly derived from the same source as those which have already been described in this group.

29 (near Duncraig). A darker and less flaggy rock, also appearing but little altered. Microscopically seems to be composed of the same materials, but with less sericite. The smaller quartz-granules are agglutinated; and the rock may with less hesitation than in the last case be called metamorphic and grouped with series I.

30 (near Balmacarra Hotel). A dull red mudstone, seemingly little altered. With the microscope a certain amount of metamorphism is perceived, as in the last case; so that it, too, may be grouped with series I. There is rather more "sericite" and ferrite.

31 (Glen Logan). A black compact limestone. This, under the microscope, is more completely crystalline than I should have expected. It is somewhat dolomitic, exhibits no trace of organisms, and contains a fair amount of opacite (graphite?) in scattered granules and streaky clots. I should expect to find it associated with rocks of the series I. type.

32 (Loch Kishorn). A dull-coloured compact limestone, traversed by numerous, irregular, thin, cherty veins. Under the microscope it appears to be an intimate mixture of calcite or dolomite with a microlithic mineral, probably quartz. The cherty veins are chalcédonic quartz. I should suggest that this also belongs to series I. group.

In conclusion I may perhaps be allowed to state that I wrote the rough draft of these notes in ignorance of the bearing of the specimens upon any theoretic views entertained by Dr. Hicks; that, upon sending it to him, my remarks upon the amount of metamorphism accorded, in the great majority of cases, with what his stratigraphical arrangement demanded, and differed only in a few instances where I myself was very doubtful, and had left an opening for further consideration. I know very little of the district; so that these notes are strictly lithological, and I have thus offered no opinion as to the geological age of the different series. As to the vexed question of the correlation of the metamorphic rocks of Scotland, I would, at present, rather say no more than this—that having regard to the teaching of Wales, Cornwall, and the Alps, very clear evidence will be needed before we can accept the dominant rocks of the Central Highlands as of Lower Silurian age.

#### EXPLANATION OF PLATE VI.

Map showing the Archaean and overlying rocks of parts of Ross- and Inverness- shires.—Scale 4 miles to 1 inch.













## DISCUSSION.

The PRESIDENT remarked upon the importance of the question discussed in the paper.

Mr. HUDLESTON agreed with the author in regarding the Glen-Docherty beds as presenting important points of difference from those lying to the eastward. He believed that in Assynt the appearance of the dolomitic limestone passing under the peculiar gneissic rock which the older geologists had described as igneous, was due to the folding over of a really lower gneiss. On the other hand, as tending to remove the *à priori* objections to the possibility of the "upper gneiss" being of Silurian age, he referred to the important discoveries made by the Norwegian geologists as to the metamorphism of fossiliferous rocks—a view also supported by M. Renard.

Prof. BONNEY described the three types which he had recognized in the specimens sent to him by Dr. Hicks and by other observers, and pointed out the probable cause of the occasional difficulty in distinguishing them. As regards the Norwegian instances of metamorphism mentioned by Mr. Hudleston, he thought that, remembering how faults, overturns, and simulation of older rocks in new rocks made of their materials, had in the past misled geologists, we should be wise to be sceptical as to the more startling conclusions of the workers whom he had named. As regards Prof. Renard, he thought there was some misconception—the Franco-Belgian rocks on which he had written were but slightly metamorphosed compared with most of the Highland schists.

Dr. G. J. HINDE stated that the Highland rocks exhibited by the author greatly resembled the Laurentian of Canada.

Prof. SEELEY asked as to the evidence on which the faults had been inserted on the map.

Mr. TOPLEY asked whether the author regarded the pebbles in the conglomerates as derived from the eastern or the western area.

The AUTHOR, in reply, said that he regarded some of the eastern and western series as the same. The faults were indicated by a total and sudden change in the characters of the rocks, as proved by microscopic examination and also by stratigraphical evidence. He remarked on the complete absence of fossils in the supposed altered Silurian rocks of the Highlands. He believed that the Norwegian geologists had fallen into error in the interpretation of their sections, some of which they confessed were equally to be explained by inversion of the strata. The few cases cited by them could, however, have very little bearing on the large question touched upon in the present paper. The pebbles in the conglomerates varied usually in accordance with the rocks upon which they reposed. Some showed clearly that rocks of the eastern types had yielded the materials.

12. *On the FOSSIL MADREPORARIA of the GREAT OOLITE of the COUNTIES of GLOUCESTER and OXFORD.* By ROBERT F. TOMES, Esq., F.G.S.  
(Read January 24, 1883.)

(PLATE VII.)

INTRODUCTION.—I have already in two communications brought before the notice of this Society some new or imperfectly understood Madreporaria from the Lias and Inferior Oolite, and have at the same time made additions to our knowledge of their stratigraphical distribution as well as to the localities where they have been met with\*.

In the present communication I propose to continue the series of papers on the same subject, in ascending order, and furnish some particulars not before noted respecting the Madreporaria of the Great Oolite of the counties of Gloucester and Oxford.

The following genera now appear as new to the Oolite of this country. *Bathycænia* is a new genus, and contains two species, which appertain to the family Astræidæ and the subfamily Eusmilinæ. *Fuvia*, *Astrocænia*, *Enallohelix*, and *Tricycloseris* are genera already established, the appearance of which in the Oolite of this country is now for the first time recorded. Two other genera already made known by me as occurring in the Inferior Oolite are here added to the list of genera of the Great Oolite. They are *Confusastræa*, which is represented by two species, and *Oroseris*, which contains only one.

In my paper on the Madreporaria of the Inferior Oolite of the neighbourhood of Cheltenham, read before the Society in May last year†, I found it necessary to make some reforms in the nomenclature of certain species. This resulted from a more extended investigation into their mode of growth and increase; and it was seen that the two very dissimilar processes, fissiparity and gemmation, had been sometimes confounded. Thus the usually accurate observation of MM. Edwards and Haime failed, in the so-called *Thecosmilia gregaria*, to distinguish between them; and the error of supposing that the species increased by division was continued by Prof. Duncan and myself. A few additional remarks will not be undesirable at the present moment.

M. de Fromentel, who calls especial attention to the necessity of distinguishing between fissiparity and gemmation, observes that the latter process produces corallites which have a new and distinct wall, whereas the corallite which is the result of fissiparity is not similarly enclosed, even when it has become separated from the parent calice. My own investigations have led me to a somewhat modified conclusion; for I believe that when gemmation takes place in species having serial calices, the young corallite is not similarly

\* Quart. Journ. Geol. Soc. vol. xxxiv. p. 179, and vol. xxxviii. p. 409.

† Quart. Journ. Geol. Soc. vol. xxxviii. p. 429.

circumscribed. Illustrations of this may be seen in *Chorisastræa* and *Phyllogyra*.

The operation of fissiparity has been very clearly explained by Fromental, and shown by him to be performed in two very distinct ways. In the one the calice is divided into two or more parts by the gradual approximation and union of two or more opposite septa. This is fissiparity in the strictest sense of the word, and it cannot be confounded with any other process. In the other process of fissiparity a gradual elongation of the calice first takes place, not merely by the extension of the ends of the septa, but also by the lengthening of the fossula—let me say, for the sake of perspicuity, in a direction north and south. Constriction of the calice then takes place in the opposite direction, that is to say, east and west. At this period the calice makes some approach in form to the figure 8; and by degrees, as the constriction continues, the calice is, so to speak, pinched in two and the division is complete. It is this process of division which has been confounded with gemmation; and in massive serial corals the two methods of increase are so very similar in appearance that it is not at all easy to distinguish the one from the other. To fully understand the distinction here mentioned, it is necessary that fissiparity and gemmation should be studied at every period during their progress; and when that cannot be done, the chances of an erroneous conclusion will be very great.

The species mentioned in this paper to which these observations will apply most fully is the *Chorisastræa obtusa*, which, until removed by me from the genus *Thecosmilia*, was regarded as a fissiparous species.

#### *Stratigraphical Position.*

The highly interesting and valuable collection of fossil corals which has contributed so largely towards the material for the following paper, consists of a beautiful and extensive series of specimens in the possession of my friend Mr. T. J. Slatter, F. G. S., of Evesham. They were collected near Fairford, Gloucestershire, by his sister, Miss Slatter, whose attention was first directed to them by the appearance of numerous corals scattered over the surface of a ploughed field. Subsequently a great many unworn and beautiful examples were obtained from excavations made for the purpose of collecting specimens.

I learn from her that some of these passed into the hands of Mr. Brown, of Cirencester; and that gentleman, in a communication received some time since, informed me that many of the corals in his collection spoken of as having been obtained at Cirencester, really came from Fairford. It is more than probable, therefore, that some of those described and figured by Prof. Duncan, and stated to be in Mr. Brown's collection, originally formed part of the Fairford collection.

Wishing for fuller information respecting the nature and strati-

graphical position of the bed from which these fine specimens had been taken, Mr. Slatter, in answer to my inquiries, informed me that the deposit was determined by Mr. John Jones, of Gloucester, to lie between the Forest Marble and the Cornbrash. It is mentioned by Dr. Lycett, in his little book on the Geology of the Cotteswold Hills, and stated on the same authority to lie at the base of the Cornbrash. Mr. Slatter further informs me that "the matrix in which the corals are imbedded is a curious white marly clay, much resembling the softer portions of the oolite marl of the Inferior Oolite." No lumps of stone or rubble of any kind appear to have been associated with the corals. This fine-grained deposit was found to lie about three feet from the surface, and was itself about a foot in thickness. In it the corals occurred so abundantly that a large number could speedily be obtained by excavating. That the matrix was eminently fitted for the preservation of the corals is evident. In many specimens which have undergone no other cleaning process than brushing in water, the details of all the external parts are so fully retained that they can be studied with as much ease as the same parts of a recent coral. But internally, as is the case with so many corals of the Great Oolite, the parts are so much altered by fossilization that structural characters cannot be observed.

Near to Burford, in Oxfordshire, by the side of the road leading to Shipton-under-Whichwood, at a place called on the Ordnance Map Caps Lodge, is a quarry in the Great Oolite which has supplied the following section:—

	ft.	in.	
1. Surface-soil .....	2	0	
2. Forest-marble .....	3	0	
3. Blue and white clay .....	1	6	
4. Hard stone in blocks having thin seams of clay .....	6	0	
5. A white and yellow mudstone, sometimes very soft, but held together by shells and corals .....	1	6	<i>Isastræa limitata</i> , <i>I. explanulata</i> , <i>Latimæandra lotharinga</i> , <i>Cladophyllia Babeana</i> , <i>Convexastræa Waltoni</i> , <i>Stylina conifera</i> , <i>Thamnastræa microphylla</i> , <i>Microsolena excelsa</i> .
6. Hard stone like No. 4, and having the character of true Great Oolite	5	0	Reduced shells in great abundance.

The bed No. 5 in this quarry abounds in corals; and the walls around the premises near it, which are built with unhewn lumps of the coral bed, have *Isastræa* and *Thamnastræa* projecting from them in great abundance. The general facies of the corals at this place much resembles that of the Fairford corals.

About ten or twelve miles to the north-west of this quarry\* is a cutting in the Great Oolite, on the Banbury and Cheltenham railway, between Bourton-on-the-Water and Cheltenham, at a place called Aylworth, in which is a thin seam of corals lying immedi-

\* North-west by west.



ately upon the Stonesfield slate. The specimens are not here numerous either as species or individuals.

Another and a very instructive coralline deposit in the Great Oolite may be seen and examined in the railway-cutting near to Stonesfield. This is no doubt the section mentioned by the late Prof. Phillips as having, "for short distances, bands of coral and nests of *Nerinea* and other shells, but rarely any approach to 'coral-reef,' or extended shell-bed"\*. A diligent search for corals in this cutting, however, has been the means of discovering a rich coral-bed, the position of which, as well as the species it contains, is shown in the following section:—

	ft.	in.	
1. Shattered oolitic stone with surface-soil on the top...	6	0	
2. Whitish shale and clay containing nodular layers of stone .....	5	0	
3. Oolitic stone in layers, separated by thin beds of soft shale .....	10	0	
4. Dense oolitic stone, very light in colour	2	6	Shells in great numbers and much comminuted.
5. Blocks of compact mudstone, sometimes soft .....	2	0	<i>Isastræa limitata</i> , <i>I. gibbosa</i> , <i>Cryptocænia Pratti</i> , <i>As-trocænia Phillipsi</i> , a <i>Montli-valtia</i> , <i>Thamnastræa Lyelli</i> in great abundance, and <i>Microso-lena excelsa</i> , <i>Anabacia compla-nata</i> , <i>Thamnastræa mammosa</i> .
6. Soft blue clay, very irregular in de-velopment, and in the middle a thin layer of hard stone which is almost wholly composed of the shells of <i>Ostræa</i> .....	3	0	A small species of oyster, probably <i>Ostrea Sowerbyi</i> , in very great abundance. <i>Mytilus sublevis</i> .
7. Rubbly soft yellow stone.....	3	0	<i>Cyathophora Bourgueti</i> very abundant.
8. Dense fine white stone, not oolitic...	1	6	<i>Nerinea Eudesii</i> , very abun-dant, and another species; <i>As-tarte angulata</i> , <i>Cardium lingu-latum</i> .
9. Oolitic stone in thick blocks, form-ing the bottom of the cutting .....	8	0	

The following Mollusca and Brachiopoda have been obtained by my friend Mr. T. J. Slatter from this cutting; and most likely they occur in beds 4 and 5:—*Fibula variata*, *F. eulimoides*, *Natica Michelini*, *Nerita minuta*, *Phasianella tumida*, *Delphinula discoidea*, *D. alta*, *Solarium varicosum*, *Leda mucronata*, *Terebratula globosa*, *T. intermedia*, and *Rhynchonella concinna*.

*Cypriocardia rostrata* and *C. nuculiformis* have also been collected there, probably from bed No. 8. All the above having been taken from the débris, their precise position can only be ascertained by the appearance of the matrix in which they are imbedded.

All these beds overlie the Stonesfield Slate, which is under the line of railway. The singular species *Cyathophora Bourgueti* occurs

\* Geol. of Oxford and the Thames Valley, p. 151.

in great plenty in bed No. 7, and is, apparently, the only coral in it, and so far as I at present know, is restricted to it\*. The great difference observable between the bed which is so rich in corals and which overlies the blue clay, and the one on which the clay rests and which contains only its one peculiar species, would seem to indicate that a complete change of conditions came in with the deposition of the clay, which was fatal to the one abundant species in the bed beneath it, and that with a return to the conditions suitable to the production and growth of corals other and quite dissimilar forms made their appearance. These forms evidently continued and thrived during the period when the whole of the Great Oolite was in process of deposition, as will be seen on reference to the comparative table which I give (at pages 173 and 174) of the species from the several localities mentioned in this paper.

My friend Mr. Beesley, of Banbury, has made known, in his valuable paper on the "Geology of the Eastern portion of the Banbury and Cheltenham Railway"†, the existence of a well-defined coal-bed in a small cutting in the Great Oolite on Rollright Heath. Nine beds are given as occurring there; and the seventh in descending order contains many corals. Of this section Mr. Beesley observes, "The section reminds one of the same beds exposed in the lower part of cuttings on the West Midland Railway (now Great Western Railway) at Stonesfield and North Leigh, which the Association visited under the guidance of the late lamented Professor Phillips three years ago."

I have several times visited this locality, and secured from the cutting a very interesting series of corals, and have also seen and examined many others collected there by Mr. Beesley, Mr. E. A. Walford, and Mr. James Windowes, of Chipping Norton. Probably therefore I am acquainted with the greater part of the species which occur there.

There are some other places in Oxfordshire where Great-Oolite corals may be met with, but where no section is observable. Steeple Barton, which has been known since the time of Dr. Plott for its fossil corals, is one of these; and Glympton, which is a village in the same district, has supplied a good number of fine specimens. At both these places the corals lie scattered on the surface of the ploughed fields. Near to North Leach, in Gloucestershire, I have also observed Great-Oolite corals scattered over a ploughed field.

The only remaining locality of which I shall speak is Epwell, near to Brailes, where I discovered in the bottom of a quarry, some years since, some large and highly coralliferous masses which had been tumbled down by the quarrymen. The corals which I obtained there were enclosed in a cream-coloured layer attached to a bed which, from its lithological character, I took to be Stonesfield Slate.

\* The same species appears and is pretty common in a "rifted" bed which immediately overlies the Inferior Oolite, in the railway-cutting at Hook Norton, Oxfordshire.

† Proc. Geol. Assoc. vol. v. no. 6.

I shall only attempt to correlate the coralliferous beds of these several localities so far as to show that they are not all on the same horizon.

Assuming that the Fairford coral-bed lies at the base of the Corn-brash, of which there can be but little doubt, the Burford one must be regarded as of a somewhat earlier date, as it is unquestionably below the Forest Marble. Both are, however, in the upper division of the Great Oolite. It is probably from about the same horizon as the Burford coral-bed that the Great-Oolite corals of the Bath district have been obtained, the late Mr. C. Moore having assured me that a great many of them were taken from beds which were the equivalent of the Bradford Clay.

But the coral-bed in the railway-cutting near Stonesfield is obviously of an earlier date than those above mentioned; for it lies under the beds constituting the great mass of the middle division of the Great Oolite. These may be seen well exposed in a quarry a little southward, while to the north of the railway are the excavations for the underlying Stonesfield Slate. The band of corals in the railway-cutting at Aylworth lies directly upon the Stonesfield Slate.

As already stated, the bed of blue clay underlying the coral layer at Stonesfield, and which is evidently an ancient oyster-bank, completely separates the overlying corals from the one solitary species, *Cyathophora Bourgueti*, which underlies it. And it may be further observed that although in the Rollright cutting, which is certainly in the lower part of the Great Oolite, the same underlying solitary coral does not occur, nevertheless it does appear in another cutting not far from Rollright in the same unassociated way, and in a position consistent with the bottom of the Great Oolite. This is, as I have already stated, at Hook Norton, in what has been denominated the "rifted" bed, resting upon the Inferior Oolite, with which it has sometimes been classed.

Assigning, therefore, to the above species, *Cyathophora Bourgueti*, a place quite apart from that of other Great-Oolite corals, the other species may be tabulated as follows:—

	1.	2.	3.	4.	5.	6.	7.
<i>Enallohelix clavata</i> .....	...	...	...	...	...	...	*
<i>Bathycænia Slatterii</i> .....	...	...	...	...	...	...	*
— <i>solida</i> .....	...	...	*	...	...	...	...
<i>Cryptocænia Pratti</i> .....	*	...	...	*	...	...	...
— <i>tuberosa</i> .....	...	...	...	...	...	...	*
— <i>microphylla</i> .....	...	...	...	...	...	...	*
<i>Stylina conifera</i> .....	...	...	...	...	*	...	...
— <i>solida</i> .....	...	...	...	...	...	...	*
<i>Convexastræa Waltoni</i> .....	...	...	*	...	*	...	...
<i>Montlivaltia Slatterii</i> .....	...	...	...	...	...	...	*
— <i>fairfordensis</i> .....	...	...	...	...	...	...	*
— <i>caryophyllata</i> .....	...	...	...	...	...	...	*
<i>Calamophyllia radiata</i> .....	...	...	*	...	...	...	...
<i>Thecosmilia Slatterii</i> .....	...	...	...	...	*	...	*

	1.	2.	3.	4.	5.	6.	7.
<i>Cladophyllia Babeana</i> .....	...	*	*	...	*		
<i>Confusastræa magnifica</i> .....	...	...	...	...	...	...	*
<i>Isastræa limitata</i> .....	*	...	*	*	*	*	*
— <i>gibbosa</i> .....	...	...	...	*	...	...	*
— <i>microphylla</i> .....	...	*	*				
— <i>Beesleyi</i> .....	...	...	*	...	...	...	*
— <i>explanulata</i> .....	...	...	...	...	*	...	*
<i>Latimæandra lotharinga</i> .....	...	...	*	*	...	...	*
<i>Chorisastræa obtusa</i> .....	...	...	...	...	...	...	*
<i>Astrocenia Phillipsi</i> .....	...	...	...	*			
<i>Anabacia complanata</i> .....	...	*	*	*	...	...	*
<i>Tricycloseris limax</i> .....	...	...	...	...	...	...	*
<i>Thamnastræa mammosa</i> .....	...	...	...	*		*	*
— <i>Lyelli</i> .....	...	*	*	*	...	...	*
— <i>Waltoni</i> .....	...	...	...	...	...	...	*
— <i>microphylla</i> .....	...	...	...	...	*		
<i>Oroseris Slatteri</i> .....	...	...	...	...	...	...	*
<i>Comoseris vermicularis</i> .....	...	...	...	...	...	...	*
<i>Microsolena excelsa</i> .....	...	...	*	*	*	...	*
— <i>regularis</i> .....	...	*	...	...	...	*	*

Column no. 1 includes the species found at Glympton, no. 2 those from Epwell, no. 3 those found in the Rollright cutting, no. 4 the Stonesfield species, no. 5 the Burford ones, no. 6 those from Aylworth, and the 7th and last column is devoted to the Fairford corals.

On looking over the foregoing lists of species it will very readily be observed that there is a strong general resemblance existing between those from all the localities given. This remark will apply to both genera and species. One species, *Isastræa limitata*, is recorded as occurring in six out of the seven localities; while *Microsolena excelsa* and *Thamnastræa Lyelli*, have been observed in four of the seven; and *Cladophyllia Babeana* and *Thamnastræa mammosa* have been taken from three localities.

Bearing in mind the great general similarity of the species in these lists, and remembering also that they occur in beds occupying very different stratigraphical positions in the Great Oolite, we are unable to conclude that these coral-beds are any thing more than the repetition of each other, and that no satisfactory division of the Great Oolite could be made by means of the coral-fauna. In this respect it differs much from the Inferior Oolite, the coral-beds in which, as I have elsewhere shown, contain each its own assortment of species.

It may perhaps be well to observe that as we proceed from Fairford to Burford, and thence to Stonesfield and Rollright (that is, in a more or less northerly direction), these coralline deposits occur in regular gradations lower in the series of the Great Oolite. To this, however, very little importance must be attached, as we cannot assume that deposits of corals may not have existed above those of Rollright and Stonesfield, or that they do not now exist, hidden in the strata, below those of Burford and Fairford.



## ZOANTHARIA APOROSA.

## Family OCULINIDÆ.

## Genus ENALLOHELIA, d'Orbigny.

M. de Fromentel, in his general work on Fossil Corals (Introduction à l'Etude des Polyp. Fossiles), makes an important addition to the definition of this genus by MM. Milne-Edwards and Haime, as given in their 'Histoire Naturelle des Coralliaires,' in the following words:—"Cloisons subentières et présentant des lobes paliformes près de la columelle." The species I have now to describe appears to fall under this definition of the genus pretty accurately; but I have failed to notice this peculiarity of the septa in specimens of either *Enallohelias compressa* or *E. elegans* from the Corallian of Nattheim. Nor has M. de Fromentel himself, in the figure of *E. minima*\*, given the least indication of a paliform lobe near the columella.

*ENALLOHELIA CLAVATA*, n. sp. Plate VII. figs. 12-14.

The branches decrease in size as they ascend, but very gradually. They are smooth, but are regularly furnished over the whole of their surface with regular and delicate papillæ; and the mural costæ are only observable near the margin of the calices, where they correspond with the septa.

The calices (fig. 14) are irregularly alternate in their position; they have a diameter equal to that of the branches, and are prominent. They are round and rather deep.

The columella is small, irregular, and has little prominence.

The septa are in six systems; and there are three cycles. Those of the primary cycle are of nearly equal thickness throughout, and approach very near to the columella, where they terminate in a pillar, which, when seen from above, looks like a rounded knob, and gives to the upper margin of the septa the appearance of a club. Their sides are ornamented with very distinct vertical ridges, which resemble the ridges seen on the septa of a great many of the *Astræidæ*; and their margins are subentire. The secondary and tertiary septa are nearly of a length, which is about half that of the primary ones. Neither the secondary nor the tertiary septa have the club-shaped termination observed in the primary ones.

Diameter of the branches  $1\frac{1}{2}$  line to 3 lines.

This species bears a little resemblance to *E. minima*, Fromentel, in having six primary septa; but it has three cycles instead of two. From *E. minima* it differs by the presence of a paliform tooth or club-shaped termination of the septa. *E. crassa* and *E. elongata* of Fromentel have only two cycles of septa, while the present new species has three. *E. crassa*, however, has the septa denticulated near the columella.

In four instances only has this species been met with at Fairford, where it was obtained by Miss Slatter. All are fragments.

But at Broughton, near Banbury, in a quarry in the Great Oolite,

\* Polyp. Cor. des environs de Gray, pl. viii. fig. 7.

I met with a specimen as long ago as in 1859, which, though too crystalline to admit of internal examination, yet has the external form well preserved, and shows that it was a thick and bushy species, and probably attained to a considerable size.

### Family *ASTRÆIDÆ*.

#### Subfamily *EUSMILINÆ*.

#### Genus *BATHYGCENIA*, n. g.

The corallum is composite, compact, turbinate, and attached; and the corallites are intimately united by their walls.

There is a common investing wall, which is costulated and sometimes has bands of rudimentary epitheca.

The calicular surface is superior and convex. The calices are more or less pentagonal or rounded, and deep. The septa are entire, thin, and project but little into the calice; and when they meet those of other calices at the top of the wall they rise into obtuse points. The primary ones meet in the bottom of the calices and form a rugged columella. At the angles where two calices meet, the walls are elevated into a kind of obtuse peak. The increase is by gemmation, which takes place only at the obtuse points just mentioned.

There is considerable resemblance between this genus and some species of the genus *Stylocœnia*, as *S. emarciata*; but it is wholly unlike other representatives of the genus, such as *S. monticularia*.

#### *BATHYGCENIA SLATTERI*, n. sp. Plate VII. figs. 1, 8.

The corallum has a depressed turbinate form, and was attached by a small surface, which in some instances was slightly peduncular.

The common wall is thick, and has broad and slightly prominent costæ, with occasional and rudimentary bands of epitheca.

The calicular surface is convex; and the calices (fig. 8) are pentagonal or hexagonal, but are much rounded by the septa filling up the corners near the top of the wall. They are as deep as wide, and have rather thin and nearly vertical walls.

The septa are smooth, and project very little from the walls of the calice. At the top of the wall, where they meet the septa of contiguous calices, they are thickened and rise into obtuse points; and this is more especially observable of those septa which meet at the point of contact of three calices. All the septa of the outer calices are continuous with the mural costæ of the common investing wall. There are six primary septa; they are thick and prominent at their outer or upper end; but they rapidly become thin and pass down the inside of the calice like a thread, and again enlarging as they pass across the bottom, unite in the centre and form a distinct but rugged columella.

The septa of the second cycle also pass like threads down the

inside of the calice, but are lost halfway down. Those of the third and only remaining cycle extend but a very little way down, and then thin off to nothing; but they, as well as all those of the other cycles, are thick at their upper and outer ends.

Gemination takes place in the angles where the calices meet; and the young calices have thick subcristiform septa (fig. 8).

In some examples the common wall is horizontal; and then this coral bears considerable general resemblance to *Isastrœa moneta* from the Cornbrash of Wast near Boulogne.

The height of the corallum is from nine to twelve lines, and the diameter from twelve to eighteen lines. The diameter of the calices is from two to two and a half lines.

At present it has been met with only in the Fairford coral-bed, and is by no means common there.

BATHYCGENIA SOLIDA, n. sp. Plate VII. figs. 9, 10.

The specimen consists of a portion only of a corallum, which, when complete, had a diameter of several inches, and appears to have been somewhat globular.

The calices are evenly scattered over the upper and convex surface; they are small, and nearly circular, but with a tendency to a hexagonal form, are rather deep, and regularly cup-shaped inside.

The septa are thick and subcristiform where they meet with those of other calices at the top of the wall; but they speedily become thin, thread-like, and straight, and have very little projection into the calice.

There are three cycles; and the septa forming the first, which are six in number, pass over the bottom of the calice and, joining in the centre, form a small but very irregular and spurious columella. Some few septa of the second cycle do the same; but others graduate away and are lost before reaching the columella.

The septa of the third cycle are very short, and appear as little more than short cristiform ridges across the top of the wall.

The calices have a diameter of one line to one line and a half.

I know of only one occurrence of this species. It was found by Mr. J. Windowes, of Chipping Norton, in the railway-cutting near Rollright, Oxfordshire, and very obligingly given by him to me.

#### Genus CONVEXASTRÆA, d'Orb.

The existence of this genus in England was for a long time to me a matter of some doubt, no satisfactory confirmation of its occurrence (as stated by MM. Milne-Edwards and Haime) having appeared. The doubt was due entirely to the particular condition or state of preservation of the specimen from which the magnified representation was taken\*. A comparison of that figure with the figures of *Convexastrœa sexradiata* given by Goldfuss†, or of *C. regularis* of

\* Brit. Foss. Cor. p. 209, tab. xxiii. figs. 5, 6 (1881).

† Petrefact. Germ. vol. i. p. 71, pl. xxiv.

Klipstein\*, or with the representations of casts of *C. portlandica*† and *C. dendroidea*‡ figured by M. de Fromentel, will sufficiently explain what is here meant.

There is no genus of corals with which I am acquainted which presents a greater diversity of appearance, according to its state of preservation, than *Convexastræa*; and the only representation I have yet seen which gives a correct idea of it in a perfect state is the one given by Klipstein of the St.-Cassian species, to which I have just referred. All the others have been taken either from casts or specimens which have lost their cristiform septal costæ or were otherwise damaged. These peculiar septal costæ are very characteristic of the genus, and distinguish it from *Cryptocænia*, to which it bears considerable resemblance, but from which it also differs in not having the summits of the corallites prominent, in having the walls hidden, and in having the distal ends of the septal costæ passing in between the distal extremities of those of contiguous calices. In their peculiar form, as well as in their connexion with the septa, the costæ more nearly resemble those of *Holocystis* than those of any other genus; but the two genera are not otherwise similar.

CONVEXASTRÆA WALTONI, M.-Edw. and Haime, Brit. Foss. Cor. p. 109, pl. xxiii. figs. 5, 6.

It occurs, but is not common, in the Great-Oolite quarry near Burford, and in the railway-cutting near Rollright, from which localities I have collected specimens; and I have a specimen picked up from the surface of a field between Bourton-on-the Water and Northleach, Gloucestershire, not far from the latter place.

I have seen corals, supposed to be of this species, which have been obtained from the neighbourhood of Stonesfield. These were nothing more than much-worn examples of the very common *Thamnastræa Lyelli*.

#### GENUS CRYPTOCÆNIA, d'Orb.

The peculiar nature of the cœenchyma of the corals of this genus is visible in all the species I have yet seen, whether from the Oolite or Cretaceous formations. In all of them it forms an important and conspicuous part of the corallum, filling up completely and symmetrically the intervals between the corallites; and in structure it must be regarded as not merely porous matter to fill up with, but as a tabulated tissue from the tabulæ of which the young corallites spring.

In another place§ I have explained my reasons for following M. de Fromentel, and regarding the genus *Cryptocænia* as distinct from *Cyathophora*; of this I shall speak more fully when I come to the latter genus.

\* Beit. zur geol. topogr. Kenntn. östl. Alpen, p. 293, tab. xx. fig. 11.

† Polyp. Jurass. Sup. pl. iii. fig. 7.

‡ Polyp. Cor. des Environs de Gray. pl. xiv. fig. 4.

§ Proceed. Geol. Assoc. vol. vi. no. 4.



## CRYPTOCÆNIA TUBEROSA, Dunc., sp.\*

*Cyathophora tuberosa*, Dunc. Supp. Brit. Foss. Cor. pt. iii. p. 15, pl. iii. figs. 15-18 (1872).

A considerable number of specimens of this coral were obtained by Miss Slatter at Fairford; and the greater part of them are in a beautiful state of preservation. I think it almost certain that the specimen figured by Prof. Duncan was one of those collected at Fairford, for reasons which I have already mentioned, and because of its abundance there and its recorded absence from the coralline deposits in the Great Oolite.

## CRYPTOCÆNIA PRATTI, M.-Edw. and Haime, sp.

*Cyathophora Pratti*, Edw. and Haime, Brit. Foss. Cor. p. 108, pl. xxi. fig. 3 (1851).

It would seem that this is far from being an abundant coral; for MM. Milne-Edwards and Haime speak of having seen only three specimens, two of which came from the Great Oolite of Combe Down, near Bath, and the other one has no locality assigned to it. I have met with three instances only of its occurrence, two specimens having been found by me in the railway-cutting near Stonesfield, and the third was taken from the surface of a field at Glympton, near Woodstock, by the late Mr. Charles Faulkner, of Deddington. It was associated with a great number of examples of *Isastræa limitata*.

The corals referred by me to this species, in my paper in the sixth volume of the 'Proceedings of the Geologists' Association,' I have now reason to believe were incorrectly assigned to it.

## CRYPTOCÆNIA MICROPHYLLA, n. sp. Plate VII. fig. 2.

The corallum is massive, more or less expanding, and has the upper surface gibbous, and in some specimens rising into dome-shaped prominences.

The calices are rather thinly placed, very small, prominent, and have very thick walls.

There are two cycles of septa; the primary ones are six in number, and extend to about two thirds of the distance to the centre of the calice. The secondary septa are merely rudimentary. The intercalicular costæ are stout, prominent, and correspond with the cycles of septa. They are of equal size; and when opposite those from other calices, they do not blend with them; and when placed alternately, they might almost be said to interlace with each other.

The diameter of the calices is about three fourths of a line, and the spaces between them about twice that measurement.

The present species differs from all the Oolite ones I have seen in having the calices smaller, the walls thicker and more prominent, the second cycle of septa rudimentary, and the intercalicular costæ of equal size, and not continuous with those from other calices.

\* This species bears so close a resemblance to *C. luciensis* that it may very probably prove to be identical with it.

In the size of the calices it corresponds more nearly with a species from the Great Oolite of Bréquerèque, near Boulogne; but the latter differs wholly in having numerous thin and continuous septal costæ. From the *C. tuberosa* of Prof. Duncan it differs in its much smaller calices and rudimentary second cycle of septa.

It occurs and is common, though perhaps not abundant, in the Fairford coral-bed.

#### Genus STYLINA, Lam.

STYLINA SOLIDA, M.-Edw. and Haime, Brit. Foss. Cor. p. 105, tab. xxi. fig. 3.

*Stylophora solida*, M'Coy, Ann. Mag. Nat. Hist. 2nd ser. vol. ii. p. 339 (1848).

A few small specimens of this species have been obtained from the Fairford coral-bed, and are in Mr. Slatton's collection. They appear to be somewhat worn, but nevertheless show conclusively that the calices in the figure given by MM. Milne-Edwards and Haime of this species are, as stated by them, a great deal too prominent. They are a little larger, too, than they are represented in the figure, and have rather thicker septa; otherwise they agree pretty exactly with the description and figure of the above-mentioned celebrated zoophytologists.

STYLINA CONIFERA, M.-Edw. and Haime, Brit. Foss. Cor. p. 105, tab. xxi. fig. 2.

I have procured this coral in a few instances from the quarry near Burford, but do not think it is common there, as it is not seen in the weathered surfaces of the rugged stones of which the surrounding walls are built, and in which so many corals are observable.

#### Subfamily ASTRÆINÆ.

#### Genus MONTLIVALTIA, Lamx.

It is rather remarkable that the genus *Montlivaltia*, which is usually so rich in species in the Jurassic formation, should be so poorly represented in the coral-fauna of the Great Oolite. MM. Milne-Edwards and Haime, in their great work on the fossil corals of this country, gave two species only. This very meagre list of *Montlivaltia* was not extended by Prof. Duncan, in his Supplement to the above work, by a single additional species of this genus, though several well-marked compound corals were added. To the two species (*M. Smithi* and *M. Waterhousei*) made known by MM. Milne-Edwards and Haime I can now, however, add three others. One of these is the old and well-known *M. caryophyllata*, the species on which the genus was established by M. Lamouroux, and the remaining two are new.

MONTLIVALTIA CARYOPHYLLATA, Lamx. Expos. méthod. des gen. des Pol. p. 78, pl. lxxix. figs. 8, 9, and 10. Plate VII. fig. 11.

Several specimens which I have examined differ from typical

examples of *M. caryophyllata* only in having the epitheca less regularly developed, and extending a little higher up the corallum. Most of the examples differ also in being a little more upright in their growth.

There is an obvious error in the description given of this coral by MM. Milne-Edwards and Haime\*. The number of cycles of septa given by them is five and part of a sixth. This statement, however, has been corrected by M. de Fromentel, who says that there are in a large calice as many as 162 visible septa†. In the calices of those I have examined there are about 108 septa.

**MONTLIVALTIA SLATTERI, n. sp.** Plate VII. fig. 20.

The corallum is broadly attached and low, and much resembles that of *M. Smithi*, but differs entirely from it in having the fossula linear. There is sometimes, but not always, a constriction around the corallum, about its middle, as in *M. Smithi*. The epitheca is strongly developed, and deeply marked with concentric wrinkles. It does not extend more than two thirds of the height of the corallum.

The calice is open, a little ovoid; and the linear fossula corresponds with the greatest diameter. The septa are exsert, and rise from the upper margin of the epitheca vertically; and forming an angle which is less than a right angle, but which is rounded, they pass in a nearly straight, inward and downward line to the fossula. They are all extremely thin and delicate; and their margins have small and irregular points, which are not thickly placed, and become very indistinct towards the fossula. Their sides are ornamented by a number of spots of very irregular form, which have very little prominence, and are placed in ill-defined vertical rows. These markings on the sides of the septa (fig. 20) are quite sufficient to distinguish the present species. There are as many as 130 to 135 septa, 18 of which extend quite to the fossula.

The height of the corallum is from 8 lines to 1 inch 3 lines, and the greatest diameter of the calice 1 inch 5 lines. The length of the fossula is from 5 to 8 lines.

It occurs at Fairford, but appears to be rare.

**MONTLIVALTIA FAIRFORDENSIS, n. sp.** Plate VII. fig. 21.

The corallum, when not rendered irregular by rejuvenescence, has very much the general form of an *Axosmilia*, but has a considerably elongated calice, and a fossula which is so much extended as to occupy fully one half of the calice.

The epitheca is well developed, but thin and almost without concentric markings. It does not extend to the edge of the calice; and its superior margin is well defined and regular. The septa are exsert; but the calice is deep, and the fossula well defined and open. The edges of the septa (fig. 21) are thin and serrated; and the teeth are formed by the upper termination of a row of closely placed tubercles,

\* Hist. Nat. Corall. t. ii. p. 303.

† Paléont. Franç. Terr. Jurass. Zooph. p. 202.

of an elongated and somewhat crescentic form, which are placed vertically just below the upper margin of the septum. Below this row of tubercles no markings of any kind appear, the sides of the septa being quite smooth. There are about 104 septa in a large calice. When the upper edges of the septa of this coral have been broken off, and the broken edges worn smooth, as is often the case, the genus to which it should be referred becomes doubtful; it then resembles an *Epismilia* rather than a *Montlivaltia*. A very few specimens only have been obtained from the Fairford coral-bed by Miss Slatter.

#### Genus CALAMOPHYLLIA.

##### CALAMOPHYLLIA RADIATA, M.-Edw. and Haime.

It occurs in the Great Oolite of the railway-cutting near Rollright, and at Epwell, between Banbury and Brailles. At both these localities it is common.

#### Genus CLADOPHYLLIA, M.-Edw. and Haime.

It is probable that the genus *Thecosmilia* will have to be submitted to division, the very different manner in which fissiparity takes place in the bushy and capitate forms (operating in conformity with their variation in form) being of sufficient importance for generic distinction. If this division were made, the bush-shaped species, such as *T. Martini* and *T. Slatteri*, would approximate so nearly to the *Cladophyllia* that they would be removed to that genus, and there would be no necessity for the creation of a new one for their reception.

CLADOPHYLLIA BABEANA, M.-Edw. and Haime, Pol. Foss. terr. Pal. p. 81 (1851); Brit. Foss. Cor. p. 113, tab. xxii. fig. 2 (1851).

It occurs in the Great Oolite at Epwell, near Banbury, near Burford, and at Aylworth on the Cheltenham and Bourton-on-the-Water Railway.

#### Genus THECOSMILIA, M.-Edw. and Haime.

##### THECOSMILIA SLATTERI, n. sp.

This is a small and well-marked species, having much the aspect of *Cladophyllia Babeana*.

The corallites are free and branching, but crowded and forming a short and close bush. They increase by fissiparity quite rapidly, sometimes dividing three or four times on nearly the same level; and as some, on the contrary, do so only occasionally, the corallum is crowded in some parts, while in others it is quite open. Notwithstanding the frequency of fissiparous division, the corallites maintain their cylindrical form, and none of the calices become much elongated preparatory to division, as in such species as *Thecosmilia*



*trichotoma* and *T. annularis*. In the present species they retain their circular outline until two principal septa have met in the centre of the calice and divided it in half, or perhaps, as is occasionally the case, three septa have equally divided it into three triangular spaces.

Externally the corallites are rather rugose, and have a well-developed epitheca, marked with irregular circular constrictions, which are not, however, the effect of rejuvenescence.

The calices are rounded and rather shallow. The septa are irregular, owing to the different ages of the calices in near approximation to each other, and owing also to the primary ones of some systems uniting in the centre of the calice while in others both primary and secondary septa meet and run together. They are thick, rude, and sometimes decrease in size inwards, while at other times they become thicker towards the centre, where a considerable number blend together and form a false columella. In some of the systems there are three cycles and the rudiments of a fourth; but quite as frequently there are only three.

It appears to be not uncommon at Fairford, and is also met with near Burford.

I entertain little doubt that the present species was figured by Prof. Duncan, in his 'Supplement to the British Fossil Corals,' as a variety of *Cladophyllia Babeana*\*.

#### Genus FAVIA, M.-Edw. and Haime.

Although no record has at present appeared of the occurrence of the genus *Favia* in the English Oolites, I have for a long time been in possession of a specimen from the Stonesfield Slate. More recently, by the kindness of Mr. J. Windowes, of Chipping Norton, I have become possessed of a species of this genus which he found in the Inferior Oolite of the railway-cutting near Hook Norton, Oxfordshire, from which place I have also subsequently taken specimens. But before this, I had myself taken a *Favia* from the Inferior Oolite, in the excavation made for iron-ore at Fawler, near Charlbury, Oxfordshire. Subsequently, that is during the present year (1882), I met with another example in the debris washed to the bottom of a gully on the south side of the valley at Crickley Hill, near Cheltenham. These several examples of the genus have not yet received that close examination which is essential for their proper determination, excepting the one from the Stonesfield Slate; but they are here mentioned as corroborative testimony of the existence of the genus in the Jurassic deposits of this country.

FAVIA PEDUNCULATA, n. sp. Plate VII. figs. 16, 17.

The corallum is small and pedunculate and has a subglobular and overhanging head. The peduncle tapers downwards to an obtuse point, by which it was attached, and is furnished with regular and delicate costæ. There is no epitheca.

\* Plate iii. figs. 1, 2, and 3.

The calices are well defined by prominent intercalicular costæ, which are thick, short, regular, and closely placed.

The calices themselves are nearly circular, but become more or less oblong and irregular in form before fissiparity takes place. The septa are rather thin, but fully maintain their size as they approach the centre of the visceral cavity.

There are six systems and three complete cycles. The first cycle joins into the columella; those of the second are two thirds the length of the first; and those of the third are only a little shorter than the second, towards which they curve.

Height of the corallum six lines, diameter of the calices from one to two lines.

The only specimen I have met with came from the Stonesfield Slate of Sevenhampton, and is now in my collection. As fissiparity is only observable in one calice, and the growth therefore presumably slow, there is nothing to support the supposition that, as the small size would seem to indicate, it is a young individual.

#### Genus CONFUSASTRÆA, M.-Edw. and Haime.

CONFUSASTRÆA BURGUNDIÆ, M.-Edw. and Haime, Pol. Foss. des terr. Pal. p. 98 (1851).

*Astræa burgundiæ*, Mich. Icon, p. 106, pl. 24. fig. 4, 1843.

A specimen in my own cabinet which agrees with the figure given by Michelin of *C. burgundiæ*, excepting that the septa are somewhat stouter, was purchased of a dealer with other Great Oolite corals, and was said to have been received from Cirencester. I am unable to give further information respecting it, except to add that it has very much the appearance of a Fairford coral.

CONFUSASTRÆA MAGNIFICA, n. sp. Plate VII. figs. 15 & 22.

One specimen only of this new and fine species was obtained at Fairford; and I describe it as follows:—

The corallum is globular, and has a short and thick pedestal. Nearly the whole of the globular part is calicular.

The calices are round or oval, and deep; and the septa are exsert outwardly, where they form a circular prominence. The space between the calices is flat and depressed.

Thesepta are rather thin, and of nearly equal thickness throughout, and have their margins regularly denticulated, each prominence being the termination of a rib, which is vertically placed on the sides of the septa (fig. 22).

The fossula is scarcely observable, but is a little elongated; and the septa meet, but do not unite, in the centre of the visceral cavity.

The septal costæ are continuous with the septa, and are of the same thickness, and connect the septa of one calice with those of another. Their margins are furnished with small tubercular dentations like those of the septa.

The first and second cycles of septa are of equal length, and meet

in the centre; the third is half the length of the first and second; and the fourth is two thirds the length of the third.

Height of the corallum  $3\frac{1}{2}$  inches, greatest diameter  $3\frac{3}{4}$  inches, diameter of the calices  $\frac{3}{4}$  inch.

This species differs from *C. burgundiae* in its globular form and in having larger calices, which are much more prominent, and with their centres much deeper, and the septa of the first and second cycles of equal length.

A second example of this species was found by me on the surface of a field east of the Duke of Marlborough's iron-works at Fawler, near Charlbury, by the side of the road leading from Fawler to Stonesfield. It is of smaller size than the Fairfield specimen, and the septa are thinner. Otherwise the two are very similar.

### Genus ISASTRÆA, M.-Edw. and Haime.

#### ISASTRÆA LIMITATA, Lamx. in Mich.

This is an abundant species at Fairfield, Stonesfield, and Rollright, and has been found also in equal abundance at Steeple Barton and Glympton, but seems to be less plentiful at Burford, where the *Isastræa explanulata* occurs in great numbers.

All the specimens in Mr. Slatter's collection have an expanded form with a thin margin and a more or less gibbous upper surface, and are provided with a rugged base surrounded by a strong and wrinkled epitheca. But the calices do not differ from those of the dendroid or foliaceous varieties which are so common in the Great Oolite of Oxfordshire.

#### ISASTRÆA MICROPHYLLA, Tomes, Proc. Geol. Assoc. vol. vi. p. 158.

Since the publication of the description of this well-marked species, I have examined, by the kindness of Mr. J. Windowes, of Chipping Norton, a specimen from the railway-cutting at Rollright. This is in a good state of preservation, and confirms the characters already assigned to the species.

#### ISASTRÆA BEESLEYI, Tomes, Proc. Geol. Assoc. vol. vi. p. 159.

Besides occurring in the Rollright coral-bed, from which the type specimens were obtained, I can now record the existence of this species in considerable numbers in Mr. Slatter's collection, and add Fairfield as a locality where it has been found.

#### ISASTRÆA GIBBOSA, Duncan, Supp. Brit. Foss. Cor. pt. iii. p. 15, pl. ii. figs. 10, 11.

In the Stonesfield cutting this species occurs, though not abundantly, and is there associated with the allied species *Isastræa limitata*. The short, thick and strongly ribbed septa, shown in Prof. Duncan's figure, are characteristic of this species. In all the specimens I have seen, the outer ends of the septa alternate very regularly with those of contiguous calices, and are never continuous with them.

This species possesses characters between *Isastræa limitata* and *Isastræa explanulata*. It also occurs and is common in the Fairford coral-bed.

*ISASTRÆA EXPLANULATA*, M.-Edw. and Haime, Brit. Foss. Corr. p. 115, tab. xxiv. fig. 3.

*Astræa explanulata*, McCoy, Ann. Nat. Hist. ser. 2, vol. ii. p. 400 (1848).

As is the case with *Isastræa limitata*, the present coral occurs both as a massive and a dendroid form. But the branching variety may be regarded as the ultimate, and therefore the most typical growth. The calices on the branches are even more superficial than those of the massive variety, and often have no depression whatever, but present the appearance of hexagonal patches of crowded septa, raised just their own thickness from the surface of the corallum. Their outward ends pass in between the outer ends of those of the contiguous calices. This interlapping of the septa is what I have not seen in any other of the *Astræidæ*; and it led me at one time to place this species in another genus. But as it is little observable on the more massive parts of the corallum, but is mostly confined to the newer growth, of course it is not a valuable character.

This coral occurs and is common at Fairford and at Burford; and I have received, by the kindness of M. Rigaux, a specimen from the Great Oolite near Boulogne.

#### Genus *LATIMÆANDRA*, d'Orb.

It is probable that the *Latimæandra* of the Secondary formations need a much more searching investigation during the earlier periods of their growth than they have as yet been subjected to, and to have their relationship with *Chorisastræa*, *Heterogyra*, and *Phyllogyra* more clearly made out.

*LATIMÆANDRA LOTHARINGA*, E. de From. Cat. Polyp. de l'Yonne, 1856; Tomes, Proc. Geol. Assoc. vol. vi. p. 160.

*Meandrina lotharinga*, Mich. Icon. Zooph. p. 100, pl. xxii. fig. 2.

Since the appearance of my paper in the sixth volume of the 'Proceedings' of the Geologists' Association, I have met with this species in the Great Oolite near Burford, and have examined specimens from Fairford in Mr. Slatter's collection. From the locality before mentioned by me (the railway-cutting near Rollright, Oxfordshire) I have also obtained a further supply of specimens, and have taken a single example from the surface of a field contiguous to the Stonesfield railway-cutting.

#### Genus *CHORISASTRÆA*, E. de From.

*CHORISASTRÆA OBTUSA*, d'Orb. sp.

*Amblophyllia obtusa*, d'Orb. Prodr. Paléont. t. i. p. 285 (1850).

*Thecosmilia* ? *obtusa*, M.-Edw. and Haime, Pol. Foss. terr. Pal. p. 78 (1851).



*Thecosmilia obtusa*, Dunc. Supp. Brit. Foss. Cor. pt. iii. p. 14, pl. i. figs. 1-4.

The coral figured by Prof. Duncan in his Supplement to the British Fossil Corals of MM. Milne-Edwards and Haime, under the name of *Thecosmilia obtusa*, was received by him from Mr. Brown of Cirencester, and, I have no doubt, was one of the Fairford corals. There are many such in the collection made by Miss Slatter at that place. These I have examined with great care, and am fully satisfied that they are not referable to the genus *Thecosmilia*.

In its general form this species is tall and turbinate, and attached by a rather narrow base. With upward growth the calice becomes lobular, and increase takes place by gemmation in the ends of the lobes. A number of corallites is the result, which may either remain attached to each other or become free. They all spring from nearly one level; and the greatest number I have seen is four. More frequently there are two or three.

#### Genus ASTROCÆNIA, M.-Edw. and Haime.

Only one undoubted Oolitic species of the genus is given by MM. Milne-Edwards and Haime in their General History of Corals\*. It is the *Astrocœnia tuberosa* of d'Orbigny, and was met with in the Inferior Oolite of Luc. Four doubtful ones are also given, namely:—the *Prionastrœa microcoma* of d'Orbigny, from the Middle Oolite of Nevizi; the *Astrœa sancti-mihieli* of Michelin, from the Middle Oolite of Saint-Mihiel; the *Astrœa crasso-ramosa* of the same author, from the same formation and place; and the *Astrœa pentagonalis* of Goldfuss, from the Middle Oolite of Württemberg. The last-named species, however, has been doubtfully referred by Becker and Milaschewitsch to the genus *Stephanocœnia*†.

M. de Fromental has described and figured a well-marked species from the Portlandian beds of Mantoche under the name of *Astrocœnia triangularis*‡. In his 'Introduction'§, only that species is mentioned as an unquestionable Oolitic *Astrocœnia*, all the others (including *Astrocœnia tuberosa*, which was evidently regarded by Milne-Edwards and Haime as a true *Astrocœnia*) being included in the list of doubtful species. Nothing new respecting the genus *Astrocœnia* appeared in the subsequently published work by the same author on the fossil corals of the environs of Gray.

From this we may conclude that the genus has been, up to the present time, represented by very few, if by more than one, undoubted Oolitic species; and the interest attending its present introduction into the English list is not lessened by its comparative rarity in the Jurassic formations of other countries of Europe||.

\* Hist. Nat. Corall. vol. ii. p. 259.

† Palæontographica, vol. xxi.

‡ Bull. de la Soc. Géol. de France, 2<sup>me</sup> ser. t. xiii. p. 859, 1856.

§ Introduction à l'Étude des Polyp. Foss. p. 233.

|| I take the present opportunity of observing that I regard some of the so-called *Astrocœniæ* from the South-Wales Lias as clearly referable to another genus. Three *Astrocœniæ* from the Lias of France, however, have been described by M. de Fromental and by MM. Terquem and Piette.

*ASTROCCENIA PHILLIPSI*, n. sp. Plate VII. figs. 6, 7.

The corallum is not very large; it is incrusting, but becomes elevated and somewhat gibbous by subsequent growth.

The calices are irregular in size and form, but are generally hexagonal. They are moderately deep, and the walls dividing them are thick and prominent. There are from eighteen to thirty-one septa; of the latter number nine are principal; they are smaller about the middle and are joined to the columella; nine others are about two thirds of the length of the first; and the remainder are short. They appear to represent nine systems, and have three cycles, of which the third is incomplete. All the septa are thick and mount onto the top of the wall, where they have a prominence corresponding to the cycle to which they belong. When unworn, their margins are regularly tuberculated; but the tubercles are elongated across the septa, and hence have more the appearance of transverse ribs than tubercles. The columella is not very prominent, but is well defined.

The corallum is from 6 to 18 lines in height; and the calices have a diameter of from 1 to 2 lines.

I have met with four examples of this coral, three of which were found attached to oysters in the Stonesfield railway-cutting, and the other taken from the surface of the adjoining field.

Compared with the *Astroccenia decaphylla* from the Cretaceous formation of Gosau, it has much the same subgibbous shape, but has larger calices, septa which are divided into a different number of systems, and the edges of which have transverse papillæ or tubercles. With the so-called *Astroccenia* of the Glamorganshire Lias it has little affinity.

## ZOANTHARIA PERFORATA.

## Family PORITIDÆ.

## Genus THAMNASTRÆA, Le Sauvage.

THAMNASTRÆA LYELLI, M.-Edw. and Haime, Brit. Foss. Cor. pt. ii. p. 118, tab. xxi. fig. 4.

This species is very abundant at Stonesfield, from which place the specimens were obtained which were described and figured by MM. Milne-Edwards and Haime. But it is rarely met with except in fragments; and this renders it difficult to make an approximate estimate of the height to which it attains. From the great difference, however, which exists in the diameter of the fragments, as well as their nearly cylindrical form, it may be assumed that they tapered upwards very slowly, and that it was a tall species.

It occurs also at Fairford, Rollright, and Epwell, and appears to be common at all those places.

## THAMNASTRÆA MICROPHYLLA, n. sp.

The general form of the corallum is that of a tall bush, perhaps about a foot in height, sections of the branches of which show that

they are either rounded or ovoid, while at the same time they are rather strongly nodulated.

The calices are very small, and evenly distributed. They are very superficial, excepting on the thinner parts of the branches, where they have greater prominence. They are round and have a small pimple-shaped columella. The septa are about twenty-four in number, and have their margins delicately but distinctly papillated. The six principal ones maintain their thickness quite up to the columella; the next six pass nearly to the columella, and become considerably thinner as they pass inwards; the remainder are short and small; but all are of nearly the same thickness at their outer ends.

The septal costæ generally form an angle where they join those from contiguous calices; but there is very little disposition to the parallel arrangement observable in so many *Thamnastrææ*, and none of the costæ anastomose.

Diameter of the calices about half a line, distance from the centre of one calice to the centre of the adjoining one three quarters of a line.

This species may be briefly described as a miniature *Thamnastræa Lyelli*, so far as the conformation and size of the calices are concerned; but the corallum is probably quite as large as in that species. In the size of the calices the present species somewhat resembles *T. mammosa*; but the septal costæ in the latter species anastomose considerably, whereas in *T. microphylla* they never do so. Moreover the papillæ of the septa in *T. microphylla* are very much smaller and more delicate than in *T. mammosa*. Only one specimen has been observed; and it was found completely filling a large mass of stone in the quarry near Burford, by Mr. T. J. Slatter, to whom I am indebted for a portion for my use in preparing this paper.

THAMNASTRÆA WALTONI, M.-Edw. & Haime, Brit. Foss. Cor. p. 120, tab. xxv. fig. 4; not Duncan, Suppl. Brit. Foss. Cor. pt. iii. pl. ii. figs. 6-9.

The fragment from which MM. Milne-Edwards and Haime drew their description and figure of this species, although possessing distinctive specific characters, was not sufficiently complete to afford a good account of the species. Many well-preserved specimens are in Mr. Slatter's Fairford collection; and while certain parts of them accord satisfactorily with the above-mentioned description and figures, other parts are so different that they might easily be mistaken for another species. It may be described as a digitate rather than a dendroid form, some individuals having at first a more or less irregular discoid base, from which arises a central dome-shaped prominence terminating in two or three finger-like processes. It was probably one of these finger-like processes that furnished material for the original description. The base is sometimes concave and covered with a thick concentrically wrinkled epitheca, completely hiding the basal wall and costæ. The newer calices (that is, those on the upper parts of the corallum) resemble those of the specimen which was figured by the original describers; but the older ones,



especially those near the base of the corallum, are quite different. They are far apart, small, round, very clearly defined, and rather prominent. The septa are short, thick, and of equal size at their outer and inner ends. The fossula is small and well defined. The septal costæ are long, very uniform in size, closely placed together, and have a parallel arrangement. They are not so stout as the septa; and a distinct notch, which often divides them from the septa, gives to the latter the aspect of a ring of pali. Both the septa and their costal continuations are very delicately and finely papillated; they might almost be said to be granulated.

Distance from centre to centre of the calices  $1\frac{1}{2}$  line, diameter of the calices 1 line.

The figures given by Prof. Duncan as of this species\*, but unaccompanied by letterpress, must, in my opinion, be referred to some other species which has the septa more strongly geniculated.

At present I have only seen specimens of this species from Fairford; but it is very common there.

*THAMNASTRÆA MAMMOSA*, M.-Edw. & Haime, Brit. Foss. Cor. p. 119.

From the surface of a ploughed field on the Stonesfield side of the Great Western Railway two examples have been obtained, which have all the calicular characteristics of the species as given by MM. Milne-Edwards and Haime, but differ considerably from their figure in the general form of the corallum. Although they possess the same nodular and gibbous upper surface, they are much more expanded and depressed.

In a bed immediately overlying the Stonesfield Slate at Aylworth, on the Bourton-on-the-Water Railway, specimens of this coral have been collected by me which more nearly approach the upright form represented in their figure. It appears at that place to be a common species. A few small specimens have also been found at Fairford; but it is probably there, as well as at Stonesfield, rather rare.

#### Genus *MICROSOLENA*, Lamx.

*MICROSOLENA EXCELSA*, M.-Edw. & Haime, Brit. Foss. Cor. p. 124, tab. xxv. fig. 5, 1851.

It was from specimens in Mr. Walton's collection that the figures and description of this species which appear in the great work on 'British Fossil Corals' by MM. Milne-Edwards and Haime were taken; and I have had the advantage of specimens from the same collection for comparison when identifying the species mentioned in the present communication. By their assistance I have determined with certainty examples from Fairford, Stonesfield, and Rollright, at all which places it is a common species.

In the early periods of its growth, *M. excelsa* is very peculiar. It then presents the appearance of a cone attached by a broad base, the summit of which is obtuse, and has a single large calice, while around the sides there is a circle of smaller calices, just as in *Genabacia*.

\* Supp. Brit. Foss. Cor. pt. iii. pl. ii. figs. 6-9.



All such examples, so far as I have observed, are attached to specimens of *Thamnastræa Lyelli*.

*MICROSOLENA REGULARIS*, M.-Edw. & Haime, Brit. Foss. Cor. p. 122, tab. xxv. fig. 6.

*Alveopora microsolenæ*, M'Coy, Ann. & Mag. Nat. Hist., ser. 2, vol. ii. p. 419.

At present I have only met with this coral, as a Great-Oolite species, at Fairford and Aylworth; and it appears to be much less abundant at those places than in the Lower Trigonogrith of the Inferior Oolite near Cheltenham.

#### Genus TRICYCLOSERIS, Tomes.

This genus was proposed by me for a coral obtained by myself from the *Margaritatus*-zone of the Middle Lias at Charmouth, and described in the 'Quarterly Journal of the Geological Society' in 1878\*. It was there described as a compound Cyclolite, having an elongated and lobular form.

Two specimens of a coral, having obviously the same generic peculiarities, were procured by Miss Slatter from Fairford; and these, while they confirm the genus, render some modification in its definition necessary. I now define it as follows:—

The corallum is oblong; and there is a flat basal plate furnished with an epitheca; the upper surface is in the form of a rounded ridge; and the calices are small and near together, and in a line along the ridge. The central one is the largest; and the others have been produced by gemmation from it on either side, somewhat as in *Dimorpharæa*. From this calicular ridge the long septal costæ slope off all round; and the outer boundary is in the form of a thick rounded edge. The septa and endotheca are perforate and like those of *Microsolena*.

*TRICYCLOSERIS LIMAX*, n. sp. Plate VII. figs. 18, 19.

The corallum is irregularly oblong; and there is a tendency to push out into lobes or corners at the ends. The under surface is concave, and consists of an imperforate basal wall, which does not extend all over the corallum and is furnished with an epitheca. The upper surface is shaped like a rounded ridge which slopes off on all sides to the thick and rounded outer margin of the corallum.

The calices are four in number in both specimens. One, which is larger than the other, holds a nearly central position, and is round and well defined and has a small but deep fossula. The others, which are near to it and are in the same line with it, are small and irregular. About thirty septa enter into and compose the middle calice. They, as well as the septal costæ, are very distinctly moniliform; and they closely resemble the same parts in specimens of *Genabacia stellifera*, from the Cornbrash of Wast, near Boulogne, but are not quite so closely placed together. These septal costæ are

\* Vol. xxxiv. p. 190, pl. ix. fig. 1.

long, thin, sometimes straight, but on some parts of the corallum curved or flexuous; and they often anastomose, especially near the outer margin of the corallum, over the rounded edge of which they pass. The synapticulæ, viewed outwardly, are cuneiform; that is to say they consist of thin horizontal perforate laminæ projecting from the sides of the septa. They do not spring from the same level on each septum, but, meeting those from the next septum, become oblique in their position across the loculus.

Length of the corallum 1 inch 6 lines, breadth of the corallum 11 lines, length of the line of calices 9 lines, height of the corallum 6 lines.

It might at first sight appear that this species is nothing more than a half developed form, perhaps of a *Microsolena*; but this is rendered very improbable by the nearness of all the calices to each other, and by the great length of the septal costæ. Moreover the young forms of the genera *Thamnastrœa* and *Microsolena*, which are common and well known, in no way resemble the present coral.

#### Genus COMOSERIS, d'Orb.

COMOSERIS VERMICULARIS, M.-Edw. and Haime, Brit. Foss. Cor. p. 122, tab. xxiv. fig. 1.

*Meandrina vermicularis*, M'Coy, Ann. & Mag. Nat. Hist. ser. 2, vol. ii. p. 402 (1848).

Only one instance of the occurrence of this coral in the Great Oolite has come to my knowledge. A specimen was obtained with the other species mentioned in this paper at Fairford, and is in Mr. Slatter's collection. It appears to be a rare species. Only two examples were seen by MM. Milne-Edwards and Haime. I have already made known its occurrence in the Inferior Oolite at Crickley\*; and the mention of the Fairford specimen adds another locality in the Great Oolite.

#### Genus OROSERIS, M.-Edw. and Haime.

OROSERIS SLATERI, n. sp. Plate VII. fig. 5.

One specimen broken in half, but otherwise well preserved, of a species of *Oroseris* is all that represents the genus in the Fairford collection. The corallum, when perfect, had a massive and somewhat lobed outline, with a greatly elevated helmet-shaped middle part, and an undersurface which had a corresponding and deep concavity. A strongly wrinkled epitheca covers the whole of the undersurface, which has lines and furrows concentrically arranged. The furrows of the calicular surface have a somewhat radiate direction from the highest part downwards and outwards, sometimes running into one another; but they curve as they approach the lower and outer edge, where they follow somewhat the line of the boundary of the corallum. They are deep, well defined, and are about equal distances apart; and there is no part of the corallum on which the calices are scattered, as in *Thamnastrœa*.

\* Quart. Journ. Geol. Soc. vol. xxxviii. p. 448.

The calices are as far apart in the rows as the rows are distant from each other. They are round; and twelve septa enter into their composition. These are equal in length, and approach near to the centre of the calice; but there is a small round and well-marked fossula. They, as well as the septal costæ, are strongly moniliform; and the beaded prominences on their edges are very distinct. The septal costæ are distinct, of equal size throughout, straight and cristiform where they pass over the prominent but rounded ridges, and none of them anastomose.

The diameter of the corallum is 4 inches, the height of the same 3 inches, breadth of the ridges between the furrows 2 lines, distance of the calices apart in the furrows 2 lines.

ANABACIA COMPLANATA, M.-Edw. and Haime, Hist. Nat. Corall. t. iii. p. 31 (1860).

*Fungia complanata*, Defr. Dict. Sc. Nat. t. xvii. p. 217 (1820).

*Anabacia orbulites*, M.-Edw. and Haime, Brit. Foss. Cor. p. 120, tab. xxix. fig. 2 (1851).

It is extremely doubtful whether this genus embraces more than one species. Every intermediate form may be met with, between the ordinary lenticular specimens of *A. complanata* and the globular one designated by MM. Milne-Edwards and Haime *A. hemispherica* so that it becomes impossible to separate the two. Again, some of the examples from the Trigonian-grit of the Inferior Oolite have a very symmetrical form, and agree so exactly in this respect, and in the delicacy of their septa, with the *A. Bouchardi* from the French Oolite that they cannot be distinguished.

Leaving them for the present as merely varieties of one species, I may mention a well-marked variety from the Stonesfield railway-cutting. It is of large size, having a diameter as well as height of more than three quarters of an inch. In form, as well as in size, it corresponds very closely with *Genabacia stellulata*, being pyramidal rather than globular superiorly, and having a deep circular depression beneath, which only occupies the centre of the base. The septa and septal costæ are relatively thick, and they anastomose much less than do those of the ordinary examples. This species occurs so abundantly in so many localities in the Great Oolite as to render any mention of them needless; but it is worthy of remark that up to this time only a single example has been taken from the very rich coralline deposit at Fairford.

## ZOANTHARIA TABULATA.

Family *THECOSTEGITIDÆ*, de From.

Genus *CYATHOPHORA*, Michelin.

After great pains and the examination of a great many specimens of one species of *Cyathophora*, obviously referable to the same genus as the one figured by Michelin, I still adhere to the recognition

of the two genera *Cyathophora* and *Cryptocænia* as proposed by d'Orbigny and afterwards adopted by M. de Fromental. The definition, however, of the two genera requires, in my opinion, some modification, which I give as follows:—

*Cyathophora*. Cœenchyma small in quantity and dense. Gemmation proceeding from it in close proximity to the walls of the corallites, if not actually from the walls themselves. Septa feebly developed, and the cycles not traceable. Calices generally much crowded, appearing at many heights, often oblique, oval, or even polygonal.

*Cryptocænia*. Cœenchyma abundant, and of a loose nature, composed of a great many dissepimental tabulæ, from which gemmation takes place quite distinct from the walls of the corallites. Septa well developed, and their cycles distinct. The calices not crowded, always round, and on the same level.

CYATHOPHORA BOURGUETI, Defr. sp. Plate VII. figs. 3, 4.

*Astræa Bourgueti*, Defr. Dict. des Sci. Nat. t. xlii. p. 380 (1826).

*Cyathophora Richardi*, Mich. Icon. p. 104, pl. 26. fig. 1 (1843).

*Cyathophora solida*, Phill. Geol. Oxf. and Thames Valley, pl. ii. fig. 1.

This coral, which is identical with the one I introduced into the British list in the sixth volume of the Proceedings of the Geologists' Association, from the examination of a single specimen supposed to have come from Garsington, Oxfordshire, occurs in great abundance in the railway-cutting near Stonesfield, but is there confined to the lower parts of the coralliferous layer, and is not, so far as I have been able to observe, associated with any other coral. I now entertain but little doubt, from the appearance of the supposed Garsington specimen, that it really came from Stonesfield. It is no doubt also identical with the species mentioned by Professor Phillips, in his work on the Geology of Oxford and the Thames Valley, under the name *Cyathophora solida*.

In young examples the corallites are directed so many ways as to suggest that they grow out of each other; but in the larger individuals they are often packed closely side by side, and the calices squeezed into an elongated or polygonal form. In the latter case there is hardly any cœenchyma; but before they have attained to a considerable growth the cœenchyma surrounds the corallites, and encases them with a layer which has somewhat the appearance of epitheca, and is of a sienna-brown colour, with a glossy fracture.

Besides Stonesfield, I have also met with this species in a bed quite at the top of the stone beds of the Hook-Norton railway-cutting. The layers there exposed are Inferior Oolite; but the one in which these corals occur, and where they are unassociated with any other species, is called the "rifted bed," and has been doubtfully regarded as Great Oolite, overlying all the others. Most likely this coralliferous layer corresponds with the lower part of the coral-bed of Stonesfield.

Becker and Milaschewitsch quote *Cyathophora Bourgueti* as occurring with another species, *C. marginstellata*, in the corallian of



Nattheim; but the figure given of the first of these shows a greater development of the septa than is seen either in Michelin's figure or in any of the numerous specimens which have come under my examination.

It is with very great doubt that I give this species a place in the Zoantharia Tabulata, not having by any means satisfied myself as to its real affinities. If I am correct in referring the present species to the one on which Michelin established the genus *Cyathophora*, the genus *Cryptocænia* will have to be retained for such species as *C. Pratti*, and *C. luciensis*. But, on the other hand, if it should eventually prove to differ from *Cyathophora* generically, then the genus *Cryptocænia* must be dropped, and a new genus formed to receive the present species: for this, *Depaphyllum* would not be an inappropriate name.

#### EXPLANATION OF PLATE VII.

- Fig. 1. *Bathycænia Slatteri*, the corallum, natural size.  
 2. *Cryptocænia microphylla*, two calices, magnified.  
 3. *Cyathophora Bourgueti*, a young corallum, magnified, showing the position of the corallites in relation to each other.  
 4. ———, a vertical section of a young corallum, showing the small quantity of dense cœnenchyma and the tabulæ inside the corallites. The peculiarity in the septa is also shown in the figure.  
 5. *Oroseris Slatteri*, a corallum, the natural size.  
 6. *Astrocænia Phillipsi*, the corallum, natural size.  
 7. ———, some calices, magnified.  
 8. *Bathycænia Slatteri*, some calices, magnified, showing the smooth cristiform septa and the mode of gemmation.  
 9. *Bathycænia solida*, some calices, magnified, showing the smooth cristiform septa.  
 10. ———, some calices, seen from above, magnified.  
 11. *Montlivaltia caryophyllata*, a septum, showing the lateral ornamentation.  
 12, 13. *Enallohelix clavata*, natural size.  
 14. ———, a calice, magnified.  
 15. *Confusastræa magnifica*, the corallum, natural size.  
 16. *Favia pedunculata*, the corallum, natural size.  
 17. ———, two calices, which have been recently formed by the fissiparous division of a larger one, magnified.  
 18. *Tricycloseris limax*, the corallum, natural size, seen from above.  
 19. ———, the corallum, natural size, seen from below.  
 20. *Montlivaltia Slatteri*, a septum, showing the lateral ornamentation.  
 21. *Montlivaltia fairfordensis*, a septum, showing the lateral ornamentation.  
 22. *Confusastræa magnifica*, a septum, showing the lateral ornamentation.

#### DISCUSSION.

THE CHAIRMAN (Dr. Gwyn Jeffreys) expressed his sense of the value of the paper. He observed that most of these corals were compound, and some of them especially peculiar to reefs, although compound Madreporaria were found living as deep as 750 fathoms. They, therefore, did not seem to very much elucidate the question of the depth of the Mesozoic sea. Simple or solitary corals cer-

tainly did not throw more light upon the question, because they occurred from shallow water to very great depths, even to 3000 fathoms.

Prof. PRESTWICH said that Mr. Brown's collection, mentioned by the author, came not from two horizons, but all from one, at a spot about 2 miles W. of Cirencester, in a zone about 6-18 inches thick, near the top of the Great Oolite.

Prof. P. M. DUNCAN confirmed the statement of Prof. Prestwich about the horizon from which Mr. Brown's collection was made. These corals, described by Mr. Tomes, were from lenticular coral-beds, not from reefs. They could hardly be very deep-sea formations, from the oolite contained in them, which seemed at the present time to be a shore-formation. It was a mistake to suppose that live reef-building corals ever occurred below about 25 fathoms. It was to be regretted that a good writer such as the author did not come more frequently among his fellow workers; for he would then have learnt that many of the statements made by him about calicular gemmation and fissiparity were already in print, and had been so from the days of Milne-Edwards. Fissiparity and gemmation were quite distinct things. Some corals keep the figure of 8 described by the author; some depart from it during subsequent growth. Unfortunately M. de Fromental, referred to by the author, was not a student of recent corals. Thecosmilian forms had been found exhibiting fissiparity; these had been actually renamed by Mr. Tomes, though the speaker had already assigned them to an existing genus. He felt doubts as to the validity of some of the genera proposed by Mr. Tomes. The coral could not be named *Confusastræa* without a section; it presented some characters allied to *Favia*. He called attention to the so-called *Cyathophoræ*, which had lost their-septa and all their internal characters. Sections, he would observe, were absolutely necessary for the study of fossil corals.









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GREAT OOLITE CORALS

Hanhart del





13. *On the Lower Eocene Section between RECVLVERS and HERNE BAY, and on some Modifications in the Classification of the Lower LONDON TERTIARIES.* By J. S. GARDNER, Esq., F.G.S. (Read January 10, 1883.)

THE Lower London Tertiaries were defined by Prestwich as consisting of three divisions. Two of these were relatively homogeneous in composition; but the third was made up of very varied materials. The extreme care and accuracy with which these divisions were traced out over the whole of the Eocene area in England, and subsequently correlated with those of the French area, led to their speedy and universal recognition. No modifications in this classification were even suggested until 1866\*, when Mr. Whitaker, while unreservedly adopting Prestwich's divisions of "Thanet Beds" and "Woolwich and Reading Beds," making, indeed, copious use of his observations, separated portions of his "basement-bed" of the London clay, where this was assigned any considerable thickness, together with a small portion of his Woolwich and Reading beds, as "Oldhaven Beds," and thus almost restricted the "basement-bed" to the inconsiderable thickness of coarser material which nearly everywhere forms the base of the London Clay. Almost the only criticism that can be urged against Prestwich's classification is that he places the "basement-bed" of the London Clay in a different group of the Eocenes from the London Clay itself, his nomenclature implying a closer relationship than he admits†. But the Survey, on the other hand, have unfortunately adopted a name ("Oldhaven") which not only does not exist on the maps, but is scarcely known at the locality, an inquiry for "Oldhaven Gap," where the beds are typically developed, being useless even at the gap itself, which is known and mapped as "Bishopstone Gap."

Stratigraphically, however, and perhaps as measures of time, these divisions leave little to be desired; and it is only from certain other points of view that this proposal to modify them may be justified.

Before entering into the details of the subject, it is advisable at least to endeavour to realize as far as possible the conditions under which the Lower London Tertiaries were produced. Although this must always to a great extent be a matter of theory and mere conjecture, a large amount of inference may be safely drawn from our actual present knowledge.

Of all facts patent to those who study the Eocenes in our own or in adjacent areas, the near proximity of land and fresh water throughout the whole series is the most obvious. Next, speaking of marine formations only, it is observed that the faunas which succeed each other stratigraphically are by no means the most closely related to each other palæontologically, but that beds separated by great vertical thicknesses contain faunas far more nearly allied than do those in

\* Quart. Journ. Geol. Soc. vol. xxii. p. 412.

† Whitaker, *l. c.* p. 413.

juxtaposition. It has come to be recognized that these interlacing faunas can be referred to two distinct types—the one perhaps best known as the fauna of the “Calcaire grossier,” and the other most readily definable as that of the London Clay. Further, it is admitted by nearly every writer on the Eocene that the latter fauna is of a more temperate or northern type than the former; and the conclusion has been repeatedly drawn that it must have belonged to a more northerly sea, completely shut off from direct communication with that sea in which the “Calcaire-grossier” fauna lived. The “Calcaire-grossier” fauna is, in England, peculiarly and wholly distinctive of the Bracklesham period, and also seems to appear first in France at about the same time; it was therefore for a long time held to be characteristic of the Middle Eocene and of nothing else. The fallacy of such views was signally demonstrated by the discovery of the “Montian system” in Belgium\*, containing at the very base of the Eocene a fauna allied to it in the closest possible manner. Since the abandonment of the belief in special creations it is perfectly obvious that slight but persistent modifications in groups of genera must be the ultimate test of the relative age of strata over the whole earth, the incoming of new types being only of value when limited areas are compared. Correlation by zones over wide areas, although extremely valuable, is misleading if perfect contemporaneity for the whole zone is thought to be implied, as zones can only represent the migrations of species following the successive spread or shifting of favouring conditions. Much of the difficulty in correlating the formations in England and America, for instance, has arisen from a disregard of these considerations.

Starting with the Calcaire de Mons at the base of the Eocene, we find the southern sea with its distinctive fauna occupying parts of Belgium, while the next fact of which we have cognizance is an extension of the northern sea, with its distinctive fauna, occupying the same ground and spreading south into France. It deposited the “Heersian,” “Landenian,” “Sables de Bracheux,” &c., whose faunas are all intimately related to those of the Thanet Sands. There is no trace of the “Montian” in England; but the rest of the Eocenes are more or less represented here, and it is with them in England only that I am able to deal. The deposits of the northern sea occupied first a limited portion of the east of the London basin only, and then, during the London Clay, extended to the utmost confines of the Hampshire basin. It is important to notice, as corroborative of the complete separation of the two seas, that though a great increase in temperature took place at some time between the Thanet Sands and the London Clay, none of the warmer “Calcaire-grossier” species found their way into the London-Clay sea, but an immigration instead took place of quite other species of Cowries, Volutes, *Nautili*, and heat-loving genera. Next, omitting freshwater formations, the southern

\* The appearance of this fauna, “anticipating its normal epoch of apparition,” is called by M. Barrande a “colony,” by M. Marcou a “*centre d'apparition d'êtres précurseurs*.” “It constitutes an exception to the laws of palæontology” (Géol. Belgique: Mourlon, 1880, vol. i. p. 193).



sea, recognizable in the Brackleshams, occupied the Hampshire basin and covered over the London Clay to within 20 or 30 miles of London. That these formations were deposited from opposite directions is apparent from their relative easterly and westerly developments. The thinning of the London Clay in Hampshire is not due to denudation by the Bracklesham sea, as it was everywhere protected by thick intervening freshwater beds, and its original thickness is preserved entire. The Barton beds show for the first time an admixture of the two faunas, though only the less tropical of the Bracklesham species remain. The Brockenhurst fauna shows an increased preponderance of southern forms, while the Hempstead fauna, if it can be said to show any thing, recalls the northern types.

Now marine faunas could only be kept distinct in adjacent areas, whose conditions of depth and sea-bottom were so similar, either by very sharply defined cold and warm currents, or by intervening land. These were clearly not separated by currents, since each formation is limited by a shore-line, and freshwater strata intervene in every case, showing the area to have become land after the deposition of each; and there is no supposition open that will explain the facts, except the continued existence of an isthmus, connecting England with the mainland, throughout the Eocene, until at least the Barton period. This isthmus was not stationary, however, but undulated from north to south and south to north without being broken through. Thus during the Thanet-Sand time it must have stretched from Dieppe along the Weald; but in the London-Clay period it could only have joined France to the south of the Isle of Wight and Purbeck; whilst in Bracklesham times it probably stretched from Belgium across the Weald to Hertfordshire. These various positions of this isthmus are not purely conjectural, except where is now sea; for its northern shore is distinctly traceable in the London Clay, and its southern shore in the Bracklesham beds. Further, the vast Eocene river, whose presence is felt in every deposit, had its estuary in the direction of the Thames valley throughout all the Lower Eocenes, but had its course diverted to the south by the change in the position of the isthmus which caused the London-Clay sea to recede; and its estuary remained in Hampshire as long as any further record of it is preserved. The detritus of the Eocene river is mainly quartzose and felspathic, and is such as to show that it probably drained a palæozoic area, while its bulk and the enormous variety of the forest vegetation imbedded in its silts leave no alternative but the belief, supported in many other ways which cannot be entered into here, that it drained a vast continent with an indefinite westerly extension, even connected in some mysterious way with America. The breadth of this river in its purely freshwater reaches is actually seen, in Hampshire and Dorsetshire, to have been at least 17 or 18 miles\*; and the extent of homogeneous or similar fluvial and estuarine deposits, stretching as they do from England over France on this area and over no other in Eocene time, shows

\* Dollfus compares its bulk in France to that of the Amazons.

its bulk to have been hardly inferior to that of the largest existing rivers.

If we admit the preponderating action of this stupendous river in the formation of all Eocenes in England and France, their stratigraphy becomes comparatively simple; but if we try to explain them by any other means, we are forced to suppose conditions which have no parallel at the present day.

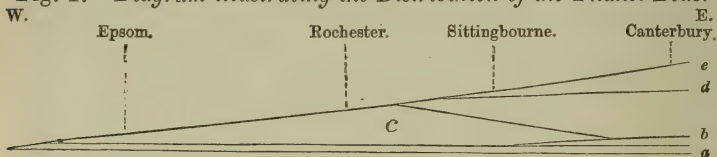
With the probable physical features of our area during the Eocene period before us, we are better able to appreciate the relative values of the divisions of the Lower London Tertiaries.

The Lower London Tertiaries are divided by Prestwich and the Survey into the purely marine Thanet Beds, the fluviatile, estuarine, and marine Woolwich-and-Reading Beds, and the marine Oldhaven Beds. The object of the present communication is more especially to question whether more than one Eocene sea encroached upon our area prior to the sea which deposited the London Clay.

### *The Thanet Beds.*

The limits of the area over which the Thanet Beds were deposited were pretty accurately traced by Prof. Prestwich; and it is quite unlikely that they ever had any very considerable extension beyond their present limits as mapped by the Survey. They are almost wholly unfossiliferous west of Rainham\* in Kent, and, indeed, present no features of interest outside the Canterbury and Isle-of-Thamet districts. The following diagram from the Survey Memoir of 1876, p. 56, explains their distribution.

Fig. 1.—*Diagram illustrating the Distribution of the Thanet Beds.*



- e.* Fine sand with occasional layers of sandstone, with fossils, sometimes silicified, thins westward, from 40 feet in thickness, and passes down into
- d.* Bluish-grey sandy marl, with green grains and fossils, thins westward, and is almost confined to East Kent.
- c.* Fine sand, without fossils ("at least but a very few remains have been found"); it is 60 feet thick in West Kent, where it forms nearly the whole of the Thanet Beds, thinning out westward in Surrey and eastward in East Kent.
- b.* Alternations of brown clay and loam, without fossils, thin and local (in part of East Kent).
- a.* The "base-bed," clayey greensand with unworn green-coated flints resting on the Chalk, thin (rarely over 5 feet), but constant.

The division *c* is typically exposed in railway-cuttings, especially about Swanley and St. Mary Cray on the London, Chatham, and

\* Otterham Quay, E. of Rainham, is the spot furthest west, except Upnor, from which fossils are recorded by the Survey and by Prestwich.

Dover Railway, and appears to be light-coloured sea-sand, with considerable cohesion, about 60 feet thick and destitute of fossils. The few localities in East Kent described by Prestwich and the Survey in which fossils have been found do not seem to differ in any important respect from the section at Herne Bay and Pegwell Bay, and need not, therefore, be further alluded to here. The fossiliferous divisions of the formation can in fact be perfectly studied along the coast, which presents by far the most perfect and accessible, as well as the most typical sections (fig. 2).

The Herne-Bay section terminates at the Reculvers, and, as restricted by Prestwich and the Survey, only exposes some 20 feet of Thanet Beds—Pegwell Bay, however, fortunately supplying a continuous section through the remaining thickness to the Chalk (fig. 5). The position of the lowest Reculver bed can be accurately determined palæontologically in the Pegwell section; but to make it quite certain, the measure of its exact height above the Chalk, which is about 70 feet, is given in a well sunk at Reculver.

The Thanet Beds rest conformably, as it is called\*, on the Chalk at Pegwell Bay, with at first a dip of about 5° S.

The base rests on a great tabular layer of flint, and is full of the usual unworn green-coated flints. It is now generally recognized that these flints have been dissolved out of the Chalk by solvent action, like that which produced the piping in chalk subsequent to its upheaval†; and the present upper surface of the Chalk is therefore not actually the same as that on which the first Eocene mud

\* Even the highest Chalk must have been greatly denuded, as it could hardly have risen to the surface before it was compressed into a solid rock without being covered with something capable of resisting wave-action. There is at least no instance of any such deposit having been preserved as a surface deposit in any Atlantic isles that have been upheaved. The Thanet Sands are as little conformable, and had as little to do with the Chalk as the Goodwin Sands.

† Whitaker, Quart. Journ. Geol. Soc. *l. c.* pp. 406, 407.

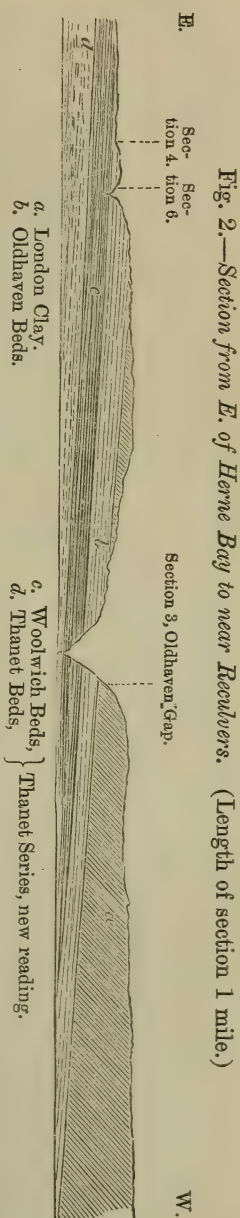


Fig. 2.—Section from E. of Herne Bay to near Reculvers. (Length of section 1 mile.)



was deposited. The waves probably acted then on a chalk coast precisely as they do now. As they undermine a cliff, the face tumbles away; and the water abrades and dissolves the chalk, leaving the flint to be rolled and drifted into bays, or onto shingle banks out to sea. The flint in any case ceaselessly travels, and is eventually ground into mud or preserved as pebbles.

Below the line of shingle beach we generally have between tides a great stretch of waterworn uneven-surfaced chalk covered and protected by fucoids and *Laminariae*; and this extends as far out below low-water as the depth permits us to see. No chalk-ooze seems ever to be reconstructed; and the carbonate of lime must therefore be carried away in solution. A great deal of the chalk bottom would apparently remain bare, as it is over large areas of the Channel, if no other sediment were brought to it; but when sediment is brought, where the sea is shallow enough to permit the growth of sea-weed, it must be originally deposited on such a seaweed-covered surface. The Thanet-beds fauna shows that they must have been deposited within the depth to which the Laminarian zone extends; and this imbedded sea-weed may well account for the peculiar character of the "blackish green mud-like sediment in which the green-coated flints are imbedded." Prestwich\* states that in burning it gives off ammonia in abundance, an evidence, he considers, of the presence in it of animal matter. This bottom-bed might of course belong to a very much older period than the rest of the Thanet Beds.

There is not the slightest evidence, however, that any elevated chalk coast-line ever came into contact with the waves that deposited the Thanet Beds in England. There are no beaches throughout the Eocene with a proportion of angular flints such as we invariably see when flint beaches are immediately derived from the chalk; nor are there any indications of old chalk cliff-lines. On the other hand, the relatively small size and the completely rounded character of all the pebbles show that they must have travelled a long way from their source, and that they may have formed part of still older deposits. The fluvial deposits show that no chalk was being cut through by the river, and the marine deposits that no chalk was being planed down on this area by the sea. The chalk cliffs of the Eocene coast-line must therefore at all our British Eocene periods have been far distant.

Above this "base-bed" we have about 19 feet 6 in. of yellowish drab sandy clay, which, though of nearly equal consistence, weathers out in bands, and on this some 16 feet of bluish slightly mottled sandy clay with decaying pyrites. The beds here become fossiliferous, and continue to be darkish sandy clay for another 34 feet, when we reach the first distinct line of drifted shells.

The shell-beds range through a thickness of about 6 feet, and enclose a band of somewhat calcareous sandy concretions; 4 feet higher there is a band of scattered black pebbles; and the section closes with some 12 feet of sand. So far the section lies in Pegwell Bay. The whole of the Reculver Thanet Beds, as limited by Prest-

\* Prestwich, Quart. Journ. Geol. Soc. vol. viii. p. 246.



wich, are comprised in this section; but, owing to extensive tracts being sometimes laid bare at low water at Reculvers, the upper beds can usually be more profitably studied there. The line of concretions is a marked feature in the cliffs as they rise at Reculvers. Below them about 12 feet of compact yellowish slightly argillaceous sand, darkening when exposed to the sea and highly fossiliferous, forms the base of the cliff. The cliffs at first trend W. by N., and the strata are horizontal, but gradually dip about  $2^{\circ}$  W. Beyond the point to Bishopstone Gap the cliffs are in a more south-westerly direction, and the dip is maintained at from  $2^{\circ}$  to  $3^{\circ}$ ; but up the chines the strata show horizontal where the face rakes S.W. by S. From the bottom of the bay the cliffs trend slightly W. by N. and the dip is again  $1^{\circ}$  to  $2^{\circ}$  W.

These sands are quartzose, somewhat micaceous and argillaceous, with green grains; ferruginous concretions are common in them, in one of which Mr. Prestwich found the cast of a most interesting pine-cone. Pieces of unrolled silicified wood are not uncommon; and one of these proved to be the magnificently preserved stem of *Osmunda Dowkeri* so accurately described and figured by Mr. Carruthers. The Mollusca are abundant, but of few species, almost wholly bivalves. By far the most abundant form is *Thracia oblata*, imbedded flat, with the two valves closed tightly. The next most abundant forms are *Pholadomya Koninckii*, which always occurs in an upright position, and *Cyprina Morrisii*. (Among the rarer forms from the Thanet Beds are several species of *Nucula*, some of which occur only at Pegwell Bay.) The only univalves that my brother, Mr. E. T. Gardner, F.L.S., who has diligently searched, and myself have met with, are a *Natica* and an *Aporrhais* with a scalaria-like spire, and a *Murex*, though some others are recorded by the Survey. These were evidently deposited in water at a depth beyond the reach of the waves, as there are few broken or even separate valves of shells, and the wood is unrolled, while this and the fir-cone and fern-stem show that they were not wholly beyond the influence of estuary water. They contain hardly any vertebrate or crustacean remains, so far as is yet known. Their deposition was probably not very dissimilar to that of some of the sediments forming on the chalk on the same coast at the present day.

At the point the concretions are 6 feet above the beach, and they and the sand below them are crowded with *Cyprina*; 200 yards east the concretions are overlain by some 12 feet of looser pale grey mottled and piped sand, on which rests a bed with silicified *Corbula regulbiensis*, a bed traceable from this point to Bishopstone Gap, on the west side of which it appears on the beach below high-water mark. It is valuable as the only land-mark by which the division between the so-called Thanet and Woolwich-and-Reading Beds can be readily picked up in the cliffs. 70 yards west a small chine occurs (fig. 6); and the concretions disappear at the base of the cliffs, but form a well-marked line of rocks cutting diagonally across the flats at low water, in a westerly direction. At another 250 yards west the beds at the base of the cliff are mottled with bright orange;

290 yards further west the *Corbula*-bed is in grey sand near the base of the cliff, and *Dentalia* occur; and 150 yards west of this, at the Gap, it is on a level with the shingle: 22 yards from the west corner of the Gap, the *Corbula*-bed appears on the beach below high-water mark and 10 feet below the base of the cliff, and soon after disappears out to sea. A very rich zone of fossils occurs at this spot, just below the *Corbula*-bed and between it and the Gap. The great *Cyprina*,  $5\frac{1}{2}$  inches in diameter, occurs here singly or in pairs of valves, and nowhere else. *Astarte tenera* very common and perfect, *Cucullæa decussata*, *Pectunculus terebratularis*, *Sanguinolaria Edwardsii*, and *Dentalium* are other shells whose range in the Thanet Beds seems almost limited to this zone, and which can only be collected at this one spot in Herne Bay. It will be observed that the fauna is much richer here than lower down; the unrolled silicified wood is replaced by rolled and bored lignitized wood; and a few very small quartz pebbles occur. None of the shells are in a living position, though the valves are very generally closed; a few valves are broken, and they seem to have been more under the action of moving water, and therefore deposited at a less depth than towards the base of the Thanet Beds. Seventy feet of muddy sand had in fact accumulated in what was originally shallow water; and unless this was wholly counterbalanced by subsidence, the bottom would naturally be raised nearer the surface.

Prof. Prestwich includes this zone with its rich group of fossils in the Woolwich-and-Reading Beds. He, as well as Mr. Whitaker, acknowledge the extreme difficulty of separating them from the underlying beds, both here and at Richborough, where the *Corbula*-zone also occurs. The former says:—"This want of clear divisional surfaces, and the occurrence of several of the same species of shells in the two series, might be considered an objection to their being thus separated. The fossils, however, taken as a group, are different from those of the Thanet Sands, whilst the sands are more siliceous and contain a larger proportion of green sand and some disseminated flint-pebbles—two mineral characters deriving some importance from their breadth and constancy"\*.

These distinctions are in themselves very slight as bases of separation between two marine formations; but even such as they are, they have since been materially lessened. Taking the marine bivalve mollusca, the only group at all perfectly known from these formations, we find, according to Prestwich, twelve species occurring in the Thanet Sand and not in the Woolwich-and-Reading Beds. On the other hand, fourteen species from the latter do not occur in the Thanet Beds. In fact six species only are cited as common to the two formations.

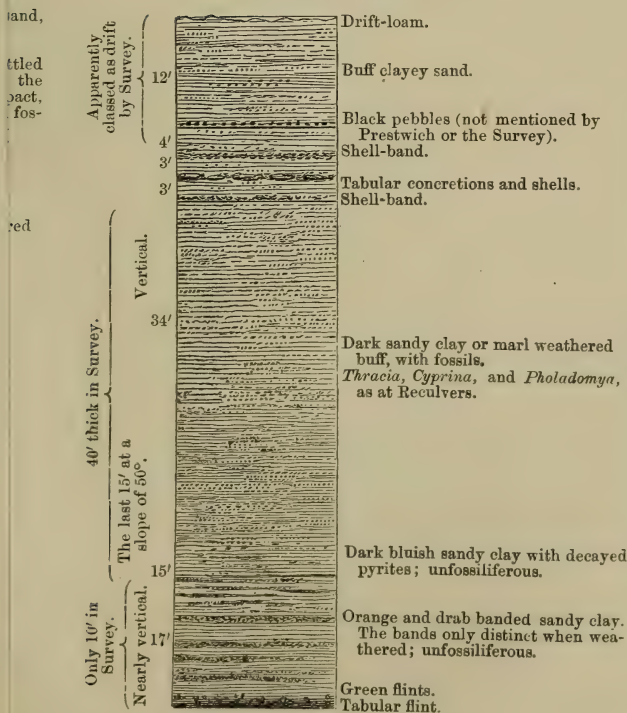
The Survey list, however†, gives very different results; and as all but two of the species have been also found at Pegwell Bay, and only admittedly Thanet Beds are present there, no errors as to the

\* Prestwich, Quart. Journ. Geol. Soc. vol. x. p. 112 (1854); see also Whitaker, Quart. Journ. Geol. Soc. vol. xxii. pp. 409, 410, 419.

† Mem. Geol. Surv. vol. iv. 1876.

erne Bay and Pegwell Bay.

Fig. 5.—Pegwell Bay.



Total 89 ft.





Figs. 3-6.—Comparative Vertical Sections of the Lower Tertiaries of Herne Bay and Pegwell Bay.

Fig. 3.—East Corner of Oldhaven Gap, facing the sea.

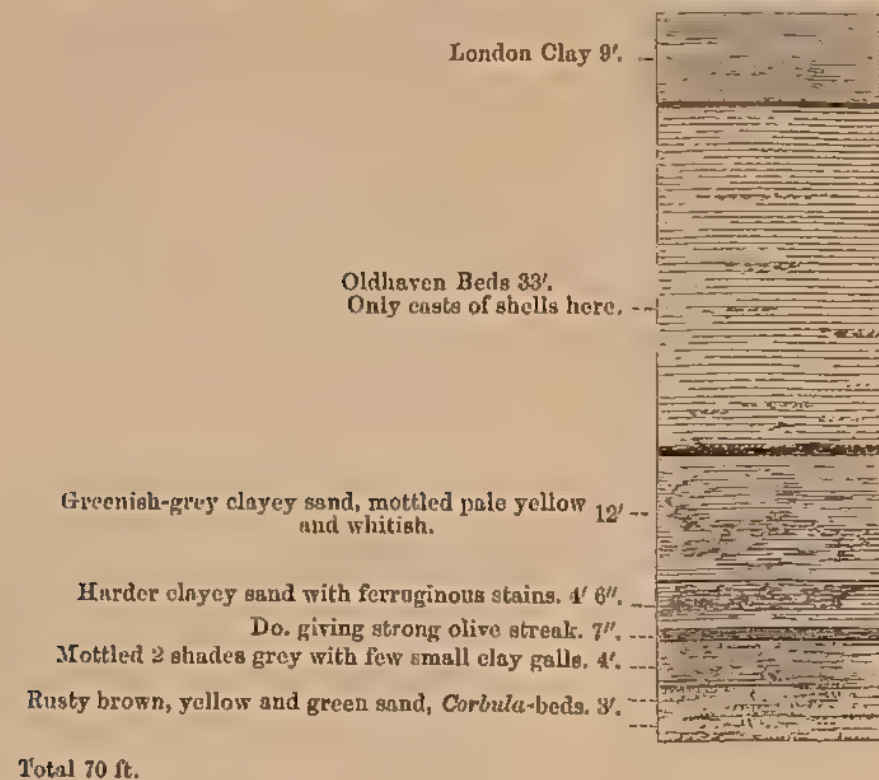


Fig. 4.—A little east of Small Chine, near east corner of Herne Bay.

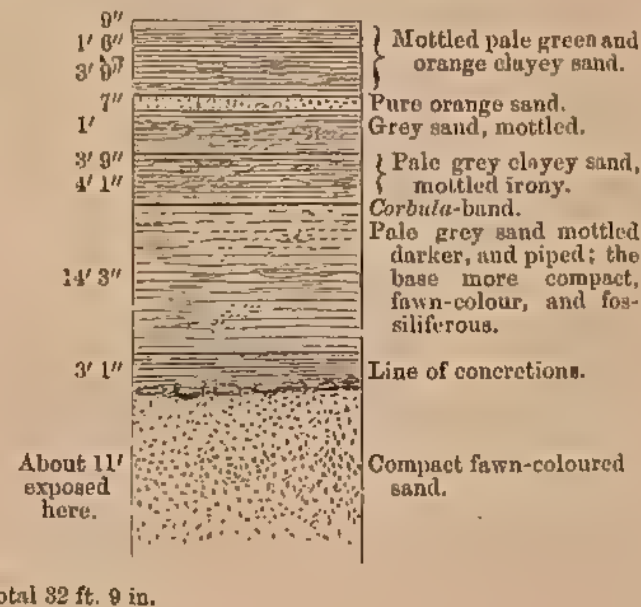


Fig. 5.—Pegwell Bay.

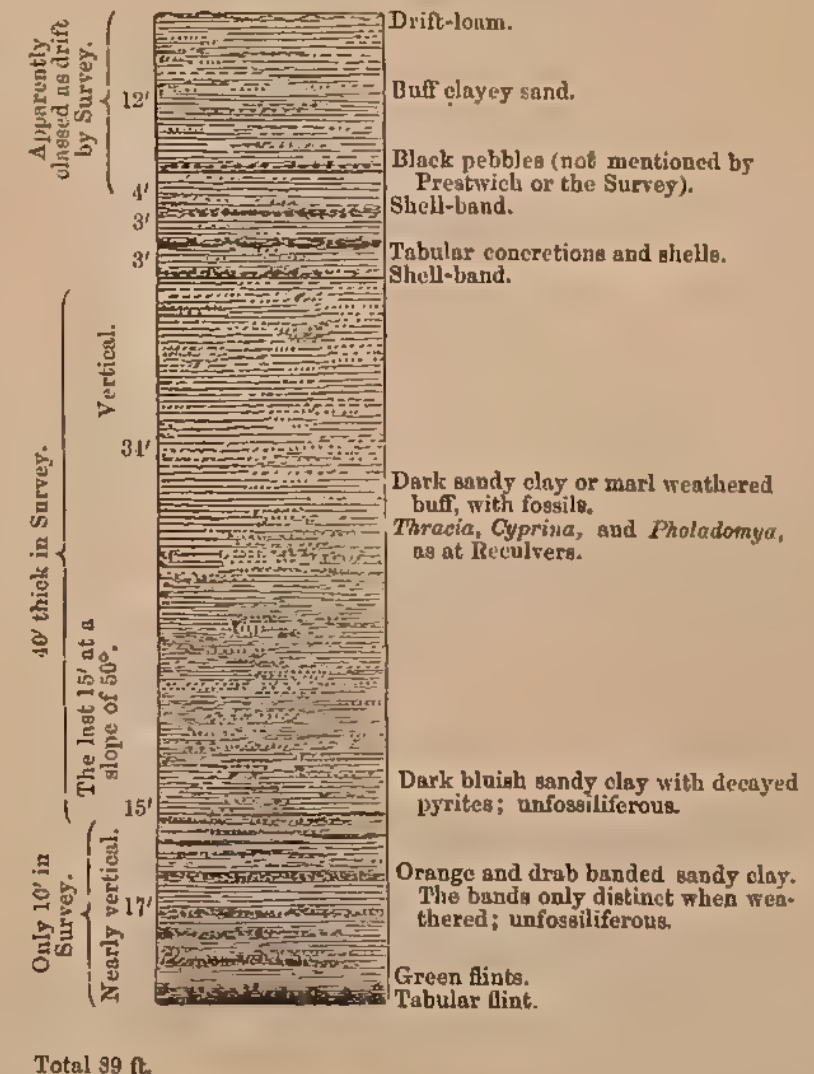
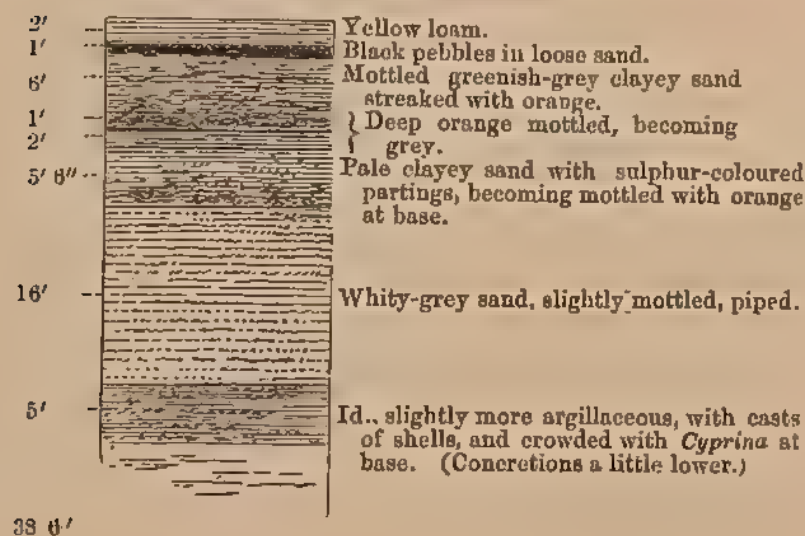


Fig. 6.—East side of Small Chine, a little west of fig. 4, showing pebble-bed.





horizon can have crept in. Of 57 specifically determined bivalves of the Thanet Sands, 13 pass into the so-called marine division of the Woolwich-and-Reading Beds, while of 12 bivalves from the latter, only two, *Cardium Laytoni*, Morr., and *Teredo antenautæ*, Sby., do not pass down into the Thanet Beds. If the Survey list is accurate, there is thus no marked palæontological break in the marine series. There is equally no perceptible difference at Reculvers in the quantity of green grains in the two sets of beds; while at Pegwell Bay a layer of black flint pebbles occurs in what is acknowledged to be Thanet Sands\*.

On these grounds I think the supposed break at this point, the obscurity and difficulty in detecting which has been remarked upon by all authors †, should be ignored, and the succeeding 20 feet of beds be regarded as an integral part of the same marine formation.

Going back to where the *Corbula*-bed first rises, we see it overlain by about 8 feet of pale clayey sand mottled rust-colour, then about 10 feet of grey mottled sand, 6 feet of fine orange-coloured sand, 3 feet pale greenish sand mottled with orange, and a foot or so of darker sand immediately under the Oldhaven pebble-bed. The arrangement is slightly varied at the small chine already mentioned (fig. 6), while at Oldhaven Gap (fig. 3) the succession is as follows:—12 feet pale greenish-grey sand mottled with yellow and white; 4 feet 6 in. slightly more clayey sand with ferruginous stains; 7 inches mottled grey and greenish sand giving an olive streak when cut; 4 feet greenish sandy clay mottled in two shades, and with a few small clay galls; and 3 feet rusty brown sand mottled with greenish yellow resting on the *Corbula*-bed. These beds are of comparatively little interest, as the few fossils they contain are not of a distinctive character. Iron pyrites, small lignitic fragments, and a few sharks' teeth are found in them. They have apparently been mud-banks in shallow water; and the pyrites may be due to decomposed sea-weed. A well-marked break occurs here, separating the next series.

### *The Oldhaven Beds.*

These beds are rather sharply separated from the underlying beds by a layer of black pebbles, sometimes 18 inches in thickness. They are almost wholly composed of fine quartzose sand, with occasional small lenticular patches of brown clay. Their distinctive character is doubtless due to the fact that whilst the lower beds were deposited under water, these were deposited between high- and low-water marks by surf. They are seen first at the top of the cliffs west of the point, and at the small chine (fig. 6) are about 36 feet above the beach. The pebble-bed is here very distinct, some of the pebbles being of large size, and all except the smallest perfectly rounded. The top line is level as if smoothed by the waves; but the lower line is uneven. The pebbles are imbedded in loose sand, overlain by two

\* The Pegwell deposits seem to have occurred nearer shore, as indicated by the presence of pebbles and broken-shell layers.

† E. g. Whitaker, Quart. Journ. Geol. Soc. vol. xxii. pp. 409, 410, 419.

feet of deep yellow slightly loamy sand, and then by quartzose sand without green grains. At Oldhaven Gap the full thickness of the beds, 26 feet, is seen, the upper surface being very uneven and the fossils casts only. The sands vary considerably in hardness, but at no particular levels. 250 yards west there are several small clay patches, the thickest a foot deep. These are sharply defined above, but below mix gradually with the sand, contain much selenite, and are cemented into sandy concretions which display beautiful ripple-marks and false-bedding. They are marked with horizontal borings from one to one and a half inch wide. The clay patches frequently rest on the pebbles, but are sometimes separated by drifts of broken shells; angular pieces of clay are occasionally included, and sometimes an indurated patch of lemon-coloured sand with iron-stains. 140 yards west the beds are 21 feet thick and very fossiliferous, with green grains towards the base. A lenticular patch of clay with sandy laminae, larger than usual, here encloses a Sarsen stone; and on the same horizon a few yards east are iron concretions crowded with shells. 160 yards west the shells approach within 2 feet of the London Clay, and there is much false-bedding; and 90 yards further west again a few concretionary blocks are seen just above high water-mark. The bedding of the sand is lenticular; and the shells are almost comminuted, and also drifted into lenticular form, both the sand and the shell-drifts being cut through again and again. A good section is seen 500 feet before the beds dip under the London Clay (fig. 7).

Fig. 7.—Section showing Junction of London Clay and Oldhaven Series.



- a. London Clay.
- b. Basement-bed.
- c. Sections across the ancient furrows of the shore.
- d. Broken shells deposited in furrows.

The Oldhaven Beds sink under the London Clay at about a mile east of Herne Bay. Their upper surface is eroded and filled in by the basement-bed of the London Clay, here only from 12 to 18 inches thick. The basement-bed is of a warm drab colour mottled with



whitish, weathering a rusty brown, giving a green streak to the tool when struck, and containing much woody matter and large green grains\*. It is a compact bed with an uneven upper surface very distinct from the overlying blue London Clay. When last seen the Oldhaven Beds appear comparatively indurated and of the ordinary buff colour of sand when dry, and greenish grey when wet.

Fossils last appear about 7 feet below the junction, and 200 feet east of the disappearance of the beds, drifted into pockets, though a little east of the latter irregular lines of fossils approach within 5 feet of the junction.

These Oldhaven Beds can be traced a long way inland without any change in character, and are immediately recognizable by their base of black pebbles. Their fauna is very rich, far richer than the Survey list of 1872 would lead us to suppose, and approximating more closely to that of the London Clay than has been admitted; but among masses of comminuted shells only one here and there is perfect. I have not observed any very local distribution among them, except in the case of a large *Aporrhais*, all the specimens of which were found close together. By far the commonest shells are *Cytherea* and *Protocardium*. The tidal and surf-action is everywhere apparent, and their origin is unmistakable; but whether they were formed, as I believe, on a coast-line, or on banks away from shore, is less apparent, the absence of unworn flints showing at least that no chalk was present in the immediate vicinity. The greater variety of the Mollusca may be accounted for by dead shells being heaped together from various depths, as we see at the present day on coasts; but the presence of a few turtle bones, taken with evidence gathered elsewhere, must also indicate that the increase of temperature had already commenced. We see by the Survey list of fossils that the fauna was intermediate between those of the London Clay and the Thanet Beds; for only two species are now not known to range beyond it; 7 of the species range downward only, 12 range both up and down, and 13 range upward only; so that it is united by 75 per cent. of its species with the London Clay, and by 50 per cent. with the Thanet Beds.

It is thus certain that there is but one break in the marine deposits of the Lower Eocene in East Kent; and I cannot help thinking that it would be far more convenient to retain the name Thanet Beds alone for the lower division. A great interval may have elapsed between these and the Oldhaven Beds, which belong palæontologically to the London-Clay series. The Oldhaven Beds might fairly be considered, as I shall show, to be a lower member of the latter series, as, indeed, was implied by Prestwich's name for them. The upper portion of the marine Thanet Beds of this part of Kent may have been, and probably was, to a slight extent contemporaneous with the fluvial Woolwich-and-Reading Beds of further west. The incoming of these cannot be traced on this coast; and there is no section apparently revealing them until the neighbourhood of Chatham is reached,

\* The lower beds of London Clay are here tenacious and blue even when weathered.

when at Upnor the shelly clays with *Cyrena* make their appearance. The sharp sands in this section (Mem. Geol. Surv. vol. iv. part 1, p. 144) I should feel inclined to place with the Thanet Beds, thus increasing their thickness there by some 30 feet. At Erith the plastic mottled clay of the Woolwich-and-Reading Beds first appears, and is some 9 feet thick. At Charlton it is absent; but at Loam Pit Hill I detected it a few inches thick\* in its proper position below all the fossiliferous Woolwich Beds. I should most decidedly place the base of the Woolwich-and-Reading Beds at this horizon, and consider all the marine shingles and sands below the plastic clay an integral part of the marine Thanet formation. In the magnificent section recently exposed in the new railway works at Croydon, the division is very clearly seen, and the whole Woolwich-and-Reading series is exposed. Below the plastic clay and above the admittedly Thanet beds is a series of clayey sands with green grains, of marine origin and with occasional fossils and flint pebbles. There is not the remotest reason, that I can discern, for separating these from the underlying series and making them a marine member of the overlying fluviatile series. As the section will probably be described by Prof. Morris and Mr. Klaassen, it is unnecessary to go into details here; but if my classification is admitted there would simply be a Lower Reading series with a very distinctive flora, and an Upper Woolwich series with a very distinctive flora and fauna—the former purely fluviatile, and the latter becoming estuarine towards its close and therefore marking a subsidence with its inevitable accompaniment, an advance of salt-water conditions up the estuary.

To meet beforehand one criticism that may possibly be advanced against this view, I may at once state that I feel no doubt that the marine Dorsetshire oyster- and pebble-beds hitherto referred to the Woolwich beds, are of London-Clay age, and mark the western shore of that sea, and not of a previous sea. The Reading Beds at Alum Bay are purely fluviatile mottled clay, and the London Clay rests directly on them; but further west the London Clay is replaced by oyster-beds, pebble-beds, and pyritous sandy clays resting on the same mottled clays on which the London Clay rests at Alum Bay. It would be rather inexplicable if the Woolwich-and-Reading series, after becoming more and more distinctly fluviatile from east to west, should again become marine in the furthest west; while on the other hand the London-Clay sea, which was of considerable depth as near as Alum Bay, must undoubtedly have possessed a shore to the west of that point.

The Thanet Beds were probably deposited, as I have shown, by a rough sea in an area out of the immediate estuary of the river, but within its influence. The area became silted up until it finally rose above the surface and became covered over with shingles and sand. The Thanet Beds close with a period of elevation, during which the Reading Beds were formed; and these were followed by a subsidence during the Woolwich period, which finally ushered in the Oldhaven and London-Clay deposits. The Oldhaven Beds may

\* Bed 9, section Loam Pit Hill, p. 127, Geol. Survey, vol. iv. pt. 1.

represent some such action (but under a rougher sea) as that which now forms the beach at Shellness, not far off; and it is conceivable that if this were an area of gradual depression, as it was at the commencement of the London-Clay period, the beaches there would advance steadily over the flat area of Sheppey on the one hand, while on the other, as they sank out of reach of disturbing waters, they would become covered up by the silt of the Thames, just as the Oldhaven beaches were covered by the London-Clay silt of the Eocene river.

The depression was maintained for an enormous period, the salt-water estuary gradually extending up the river-valley as far as the western limits of the Hampshire basin, and deepening at Sheppey until nearly 500 feet of silt was deposited. The Thames mud at the same spot is already nearly 100 feet thick, and this on the present shore and consequently out of the main channel. The advance of the London-Clay sea was distinctly not due to any planing action, but to gradual subsidence; for the London Clay always rests on other Eocene formations, though elsewhere and far off the Chalk must have been incessantly attacked, as it is now, by the waves. Beaches such as the Oldhaven deposits could only be formed near the mouth of the river; and we accordingly see that they diminish and disappear in Hampshire and to the west.

Beaches may equally have been formed along the shore of the Thanet-Sand sea, and left stranded when it retired; and it is not always clear to which agency many of the vast aggregations of shingle and sand between the Thanet Beds and the London Clay may belong. They are, however, an integral portion of one or other formation, and should not be recognized as a separate formation at all approaching other divisions of the Eocene in value. The same may be said of the so-called marine Lower Bagshots, which mark the retreat of the London-Clay sea. That any vast lapse of time occurred between the Thanet-Sand and London-Clay period I do not at present believe, seeing that the enormous change of temperature that almost suddenly took place between them, a change which drove the indigenous flora northward to Greenland, would amply account for the difference in their faunas. The Woolwich Beds at least, however, were formed during the interval, and the European Tertiaries may furnish data as to its duration.

I submit this as a simpler explanation of the formation of the Lower London Tertiaries, and a more definite classification of their complicated changes, than that hitherto prevailing. If accepted, it can by no means diminish the value of any work previously accomplished; and, while involving no new terms, it renders the recognition of the divisions in the field far easier.

#### DISCUSSION.

Prof. PRESTWICH remarked upon the value and beauty of the collections made by Mr. Gardner. At the time he had written his own paper the exact horizon of many forms had not been determined, and the careful collecting of Mr. Gardner would clear up many of these doubtful points. He did not, however, think that the theoretical views propounded in the paper were of equal novelty



and interest. Every one admitted the great gap between the Chalk and Thanet Sands, and that the Thanet Sands, Woolwich Series, and Basement Beds were, like the "Landenian System" of Belgium and the "Sables Inférieurs" of France, merely minor subdivisions of one continuous formation, with variations caused by local subsidences and elevations. He had recently found marine shells as far west as Reading. The fluviatile Woolwich Beds pass at Herne Bay into marine beds with a poor fauna. In Belgium and France these beds contain a much larger marine fauna than our own. He thought the actual facts did not support the views of the author.

Mr. WHITAKER stated that the separation of the Oldhaven Beds on the Geological Survey maps was due to the fact that they were clearly recognizable, and capable of being followed and mapped. He found no reference in Mr. Gardner's paper to the fact that the Oldhaven Beds are not always marine, but sometimes fluviatile and fluvio-marine. He agreed that the apparent conformity of the Chalk and Tertiary in England does not prove that there is no gap. He had clearly recognized long ago that in Eastern Kent there is no marked separation between the Thanet and the Woolwich Beds. The three members of the Lower London Tertiaries are really very small and insignificant subdivisions. He thought that the perfectly rolled condition of the flint pebbles of the Oldhaven Beds pointed to the conclusion that they were formed, not on a beach, but a little way out at sea. The Woolwich Beds sometimes lie on eroded surfaces of the Thanet Beds, which is opposed to the author's views. So also is the alternation of plastic clays with shelly Woolwich Beds, which makes it impossible to divide the Reading from the Woolwich Beds. He remarked on the local character and distribution of the Oldhaven Beds as compared with the Woolwich-and-Reading Beds; in some places the former rest unconformably on the latter, on the Thanet Beds, and on the Chalk.

PROF. SEELEY remarked upon the important fact pointed out by Mr. Sorby that the Thanet Sands were mainly derived from granitic rocks. He thought the existing classification was a convenient one, especially for teaching-purposes. He doubted the accuracy of the general view supported by the author, namely that the materials of these strata were derived from the west. He himself thought that both palæontological and physical evidence pointed to the conclusion that the materials were derived from the east. He doubted not only the author's conclusions with regard to the climates of these different periods, but all conclusions of the same kind.

The AUTHOR stated that he had found a very characteristic flora under the mottled clays of the Reading Beds, a flora also found at Newhaven and in Greenland. He believed the mottled clays to be purely freshwater deposits. These beds are traceable at Lewisham and Blackheath under the Woolwich Beds. He maintained that there is no means of comparing the faunas of the two beds; but the floras are dissimilar and show a marked climatal change. He did not agree with Mr. Whitaker and the Survey that the Bromley leaf-beds belong to an Oldhaven freshwater series, but thought them to be on the same horizon as the Woolwich flora.



14. *On the LOWER CARBONIFEROUS ROCKS of the FOREST of DEAN, as represented in TYPICAL SECTIONS at DRYBROOK.* By E. WETHERED, Esq., F.G.S., F.C.S. (Read February 7, 1883.)

[Abridged.]

IN this paper I shall first refer to a series of arenaceous and calcareous shales which lie between the Old Red Conglomerate and Lower Limestone Shales, and which represent the true basis of the Carboniferous rocks in Gloucestershire. (2) I shall refer to some beds in the Lower Limestone Shales which may serve as horizons for correlation with other coalfields. (3) I shall consider some features in the Millstone Grit.

1. The Old Red Conglomerate at Drybrook dips to the south-east at an angle of  $38^{\circ}$ . It is made up of "vein-stone" quartz\* pebbles, grains of ordinary quartz, measuring about  $\cdot 021$  of an inch in diameter, plates of mica, and a little felspar. Of the quartz grains about fourteen per cent. can be recognized as crystals; but the rest are waterworn. The grains are coated with oxide of iron; but on this being removed by acid, cavities are exposed to view, some of which contain bubbles. In addition to the deposition of oxide of iron on the grains, silica is often found attached to them in minute well-defined and clear crystals.

The Old Red Conglomerate passes conformably into a series of loose sandy beds and light and greenish-coloured calcareous shales, dark shales being absent. A section of these beds, carefully measured by the late Mr. John Jones and Mr. W. C. Lucy, F.G.S., showing 247 feet and 108 divisions, appeared in the Proceedings of the Cotteswold Club for 1867. They are there termed "Transition Beds." Sir H. De la Beche has given sections of the junction of the Lower Limestone Shale with the Old Red Sandstone rocks†, and has noted strata similar to the beds to which I am referring; but they appear to have been much less developed in the localities where his sections were made than is the case at Drybrook. He has, however, referred them either to the Old Red Sandstone or to the Lower Limestone Shales.

The sandy beds and calcareous shales are characterized by the rapid succession of beds and by the variety of colour. In order to examine them minutely, five beds were selected as typical, and specimens taken from them; the first was from near the base, and the others from various parts proceeding upwards.

No. 1 was a light-coloured bed with but slight cohesion between the grains composing it. It contained a considerable quantity of mica

\* This term, vein-stone quartz, is used by Sir H. De la Beche, *Memoirs Geol. Surv.* vol. i. p. 64.

† *Memoirs of the Geol. Surv.* vol. i. "Formation of Rocks in the South-west of England," p. 142, and in other parts of the monograph.

of white and greenish-brown colour. Felspar was present in fairly well-defined crystals. The quartz contained cavities similar to those found in granite. The minerals occurred in clusters, and appeared to have been derived from granitic rocks. The larger grains of quartz averaged about  $\cdot 007$  inch in diameter.

No. 2. Colour light brown; more compact than the last. Same minerals present, but clusters less numerous. The grains, as a whole, more waterworn, the larger ones averaging about  $\cdot 008$  inch in diameter. Calcareous fragments present.

No. 3. From about the centre of the series. A calcareous shale of light colour with a pale tinge of pink, very micaceous. It gave the following chemical composition on analysis:—

Silica .....	76.60
Alumina.....	8.30
Oxides of iron .....	2.13
Lime .....	5.00
Oxide of manganese .....	.13
Carbonic acid .....	5.00
Magnesia .....	1.85
Alkalies .....	1.12
Loss on ignition .....	.35

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100.48

No. 4. Contained small "vein-stone" quartz pebbles, similar, except in size, to those in the Old Red Conglomerate. Minerals present the same as previously noticed. Quartz grains more waterworn than before observed; the larger ones averaged about  $\cdot 012$  of an inch in diameter. It gave the following chemical composition on analysis:—

Silica .....	92.66
Alumina.....	2.46
Oxides of iron .....	1.13
Lime ..	.86
Oxide of manganese .....	.13
Carbonic acid .....	.45
Magnesia .....	trace.
Alkalies .....	1.00
Loss on ignition .....	1.20

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99.89

No. 5. Colour yellow; could not be distinguished, lithologically, from some beds of Millstone Grit in the neighbourhood, except that the grains of quartz in the latter are more waterworn. Same minerals present as before noticed, but a greater preponderance of quartz; the larger grains measured about  $\cdot 011$  of an inch in diameter.

2. The beds to which I have just referred are succeeded by the Lower Limestone Shales, the nature of which is shown in the following section:—

No. I.—Section of a portion of the Lower Limestone Shales  
exposed in Quarry near Drybrook, Forest of Dean.

Petrology.	ft. in.	Chief Fossils.
Not exposed.		
Blue limestone .....	3 0	Fossils scarce.
Impure limestone .....	4 0	No fossils.
Limestone .....	4	<i>Athyris Roissyi</i> .
Argillaceous beds .....	8	<i>Rhynchonella pleurodon</i> .
Limestone .....	7	Encrinites, <i>R. pleurodon</i> .
Rhynchonella-bed .....	7	<i>R. pleurodon</i> abundant.
Argillaceous and calcareous bands...	1 0	Encrinites in the calcareous bands.
Limestone .....	5	Encrinites, Polyzoa.
Argillaceous beds .....	1 4	No fossils visible.
Polyzoa-bed, impure limestone ...	2 5	Polyzoa numerous, with a profusion of Encrinites.

Limestone and beds of clay, not fully exposed.

Sandy beds .....

To the "Polyzoa-bed" in the above section I desire to direct special attention. It is a cream-coloured impure Limestone, crowded with the stems of *Poteriocrinites crassus* (Miller), which have the peculiarity of being insoluble in cold acid. There are also a few *Athyris Roissyi* and spines of *Productus*; but the most characteristic fossils are three species of Polyzoa which are also common to the Red Limestone of Arran\*.

The next bed of special importance in the above section is the one which I have termed the "Rhynchonella-bed." It is an argillaceous deposit, seven inches thick, and is characterized by the number of *Rhynchonella* which occur in it. Specimens of these shells were sent to Mr. Davidson, F.R.S., to whom I am indebted for the determination of them; he wrote to me saying that they were a small variety of *R. pleurodon* "much crushed." Besides these fossils, the bed contains *Athyris Roissyi*, fragments of perforated Brachiopod shells, spines of *Productus*, and a small *Serpula*. There are also thin yellow-coloured disks, the larger ones averaging about .008 inch in diameter. Some of these resemble sporangia; but I leave the matter open for further investigation. A sample of the bed was sent to Dr. Hinde, to whom I am under an obligation for much kindness in giving me his opinion on matters referred to him. Dr. Hinde saw signs of what appeared to him to be fragments of the jaws of Annelids; and he recommended me to search further into the matter. This I did, and was rewarded by finding one perfect specimen and several fragments; and I now have the authority of Dr. Hinde for saying that the jaws found are those of Annelids.

The whole of the Lower Limestone Shales is not exposed at Drybrook; and the same remark applies to the Mountain Limestone. The close of the formation is represented by shales and limestone, a part section of which I append; it was taken many years ago by Mr. Lucy, who has kindly given me permission to use it.

\* These fossils were submitted to Dr. Wright, F.R.S., and Mr. John Young, of Glasgow, who kindly determined the species to be *Rhabdomeson gracile*, *Ferestella tuberculata*, and *Ceripora similis*. They were referred to by Dr. Wright in an appendix to this paper.

No. 2.—*Section showing a portion of the upper part of the Carboniferous Limestone at Drybrook, Forest of Dean.*

	ft.	in.	1	
		9		
		8	2	Clay.
Cream-coloured Limestone, much resembling Low- er Lias.	2		3	Stone.
	3		4	Clay.
	3		5	Stone.
	2½		6	Clay.
	8		7	Stone.
	2		8	Clay.
	10		9	Grey hard Limestone.
	1	6	10	Clay and thin beds of concretionary Lime- stone.
	1	2	11	Hard Limestone with masses of Coral.
	6	0	12	Clay and Grey Limestone with occasional Sand- stone and Shale.
	1	6	13	Hard grey Limestone.
	2	0	14	Ditto.
	1	0	15	Shale.
	1	3	16	Limestone.
		6	17	Shale.
	2	0	18	Limestone.

Dip 36°, N.N.W. to  
S.S.E. Elevation about  
650 feet.



3. The Millstone Grit overlies the Carboniferous Limestone at an angle of  $45^{\circ}$ ; and the lower beds have some features which are not common to the upper. Taking first the former, we find (1) that they are built up of fine-grained sandstones together with reddish-coloured flagstones. (2) There are casts of shells and of other forms of life. (3) Remains of a *Lepidodendron* allied to *L. Griffithii* (Brongn.), are very numerous. The sandstones are composed almost entirely of quartz, with a very small quantity of mica and felspar. Coming to the upper beds, they consist of sandstones, the grains of which are well waterworn; but no signs of life of any kind have as yet been found in them. In some of the beds "vein-stone" quartz pebbles occur; and these when compared with those in the Old Red Conglomerate seem to be identical, except that they are more rounded. One bed, at Sudley, is so full of these pebbles that when first discovered it was taken for the Old Red faulted up\*, but on examination was found to be regularly interstratified with the other beds, about the determination of which there was no question or doubt. The following is an analysis giving the chemical composition of a typical representative of the Drybrook Millstone Grit; and for the sake of comparison an analysis of the same formation from Brandon Hill, Bristol, is also given.

	Forest of Dean.	Bristol.
Silica .....	98·06	97·80
Alumina .....	·30	·47
Oxides of iron .....	·50	·80
Lime .....	·33	·44
Carbonic acid .....	·30	·39
Alkalies.....	trace.	.....
Loss on ignition (carbon) .....	·20	·17
Moisture .....	.....	·22
	<hr/> 99·69	<hr/> 100·29

Reviewing the evidence of sequence, the Old Red Conglomerate, the many-coloured sandy beds and calcareous shales which immediately follow, and the Millstone Grit, all seem to have been formed by materials derived from the same source, namely ancient granitic rocks; but the sediment and pebbles have been subjected to various degrees of mechanical attrition: the evidence of this is furnished by the occurrence of the same minerals in these rocks, and especially by the "vein-stone" quartz pebbles. There is no unconformability; and therefore there is no reason for supposing that one set of beds can have originated from the denudation of the other: this being so, there is no alternative but to accept the view which I have expressed.

As to the correlation, I will only say that the sandy beds and calcareous shales, between the Old Red Conglomerate and Lower Limestone Shales, have no Old Red affinities, and occupy the position of the Calcareous Sandstone group in Scotland; the lower beds of

\* I have since come across the same bed in another place regularly interstratified with the Millstone Grit.

Millstone Grit, together with the upper portion of the Carboniferous Limestone, occupy the horizon of the Yoredale rocks of the North of England. This matter I shall treat of in a future paper.

In conclusion, I desire to return my thanks to Mr. W. C. Lucy, F.G.S., for his kindness in drawing my attention to the rocks referred to in this paper, and for his assistance in working them out. Mr. Lucy is not, however, in any way committed to the views which I have expressed. I also tender my thanks to Mr. F. D. Longe, F.G.S., for the ready way in which he placed his specimens from the Clifton Polyzoa-bed (Stoddart) at my disposal.

The whole of the strata mentioned are shown in the following section :—

No. 3.—*Vertical Section of the Carboniferous Strata in the Forest of Dean.*

Description.	Approximate thickness. ft.	Characteristic Fossils.
Coal-measures (do not come in at Drybrook).	3243	Plant-remains.
Millstone Grit, made up of well-rounded grains of quartz.	370	None yet found.
Lower Millstone Grit, flagstones and sandstones.	100	Casts of Mollusca, plant-remains.
Upper Limestone.	116	Corals &c.
Carboniferous Limestone; hamatite in upper portion.	360	<i>Producti</i> , <i>Spirifera</i> , &c.
Lower Limestone Shales. ....	130	Encrinites, <i>Rhynchonella pleurodon</i> , <i>Athyris Royssii</i> , Polyzoa, Annelid-jaws.
Many-coloured sandstones and calcareous shales.	247	No fossils identified.
Old Red Conglomerate.		

#### DISCUSSION.

Mr. ETHERIDGE differed from the author as to two points in his paper. (1) He thought the term Calcareous Sandstone was inapplicable to the series described by him; for neither lithologically nor palæontologically did they correspond with the Tuedian or Cement-beds of the north. Two fossils came from the latter and were always present, an *Athyris* and a *Nautilus*: these were wanting in the beds described by Mr. Wethered. (2) As regards the Upper Limestone Shales, there were Upper Shales in the Bristol district; but these differed palæontologically from the Yoredale series of the north, and it required better proof in order to identify them. As regards the Polyzoa-bed, there was no doubt of its position; but it differed much from that described by Stoddart at Bristol. He explained the reason why so large an area was occupied by Millstone Grit. The Yoredale beds could hardly come in there, as the limestone was a deep-sea deposit.

Mr. TOPLEY said the paper showed great care and accuracy; but

in the question of correlation there were not only the difficulties mentioned by the last speaker, but further the Calciferous Sandstone of Scotland represented a large part of the true Carboniferous Limestone of England. The Yoredale series also represented a part of the Carboniferous Limestone series.

Mr. DE RANCE also objected to the correlation. As regards the Yoredale beds, though present in Derbyshire they are absent in North Wales and around the Shropshire coalfield. The Millstone Grit, when traced S.S.W., thins out, and is missing in North Wales in one area. Going further south, the Millstone Grit comes in again; but the Yoredale rocks do not. The name Yoredale was to be regretted; for the Yoredale limestones of the typical valley of the Yore are really true Carboniferous Limestone, and correspond palæontologically and physically with it.

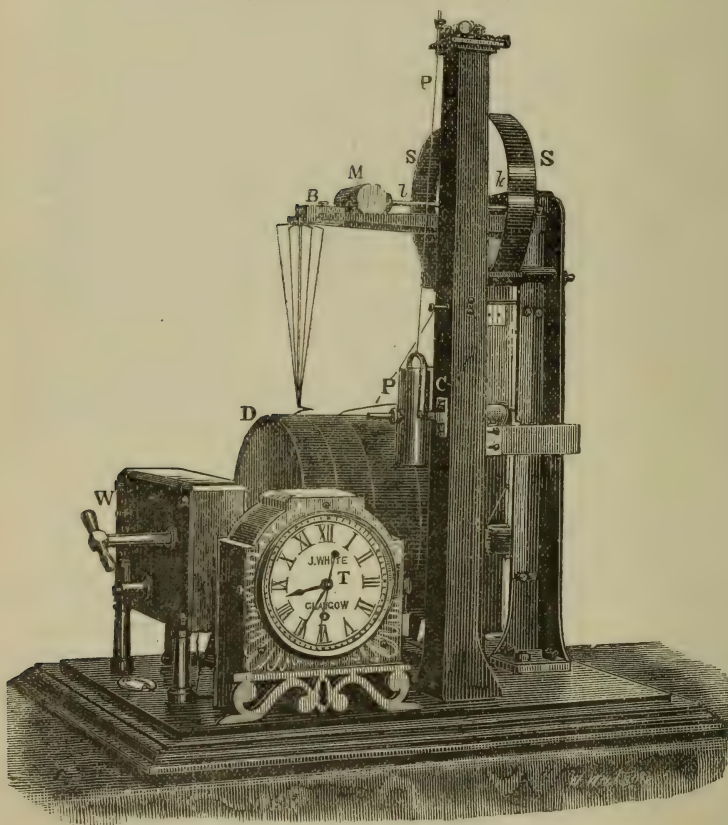
Mr. WETHERED, in reply, said that, if the beds in the Forest of Dean occupied the position of the Calciferous Sandstones of Scotland, the probability was that they corresponded with them in point of time. The palæontological argument also seemed contradictory; for Mr. Etheridge said the Calciferous Sandstone had only two fossils, but Mr. Topley asserted there were plenty. As for Mr. De Rance's arguments, he did not see that lithological similarity could be expected in the northern Yoredales and in these southern rocks. Even in the latter region the same series underwent a change in a comparatively short distance. All he said was that they differed from the Millstone Grit and were in the position of the northern Yoredales.

15. *On GRAY and MILNE'S SEISMOGRAPHIC APPARATUS.*

By THOMAS GRAY, Esq., B.Sc., F.R.S.E. (Read March 7, 1883.)

THE apparatus a description of which forms the chief subject of the present paper, is intended to give a complete record of the nature, magnitude, direction, and frequency of the motions of a point of the earth's surface during an earthquake, and at the same time to record the time of occurrence and the duration of the earthquake. The apparatus has been made by Mr. James White, Glasgow, and is to

Fig. 1.—*Gray and Milne's Seismographic Apparatus as set up.*  
(Scale about one twelfth.)

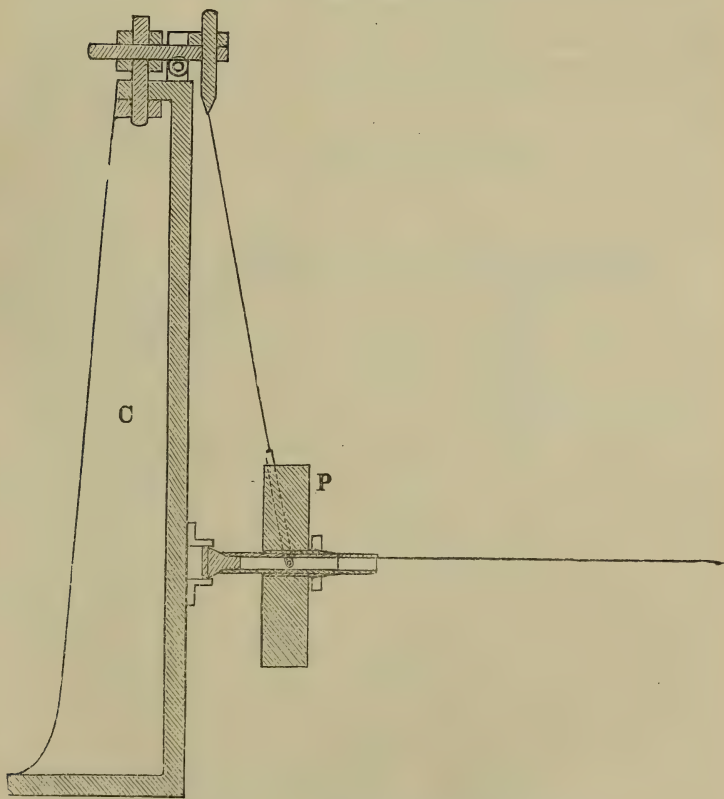


be used by Prof. Milne in his investigations as one of the committee appointed by the British Association for the investigation of the earthquake phenomena of Japan.



The instrument is suited for recording motions of the earth which are under one centimetre on either side of its normal position, while the period of oscillation is less than one second. The instrument may be adjusted to register motions having a longer period; but it is not expected to be called upon to do so. The actual motion of the earth is to be derived from a record of three separate components of the motion—two horizontal and at right angles to each other, and the other vertical. The horizontal components are recorded by a pair of conical pendulum-seismographs (see Phil. Mag. Sept. 1881), one of which is shown at P, figs. 1 & 2. These instruments are considerably simpler in form, and can be more readily adjusted, than the instruments described in the paper above referred to. They consist

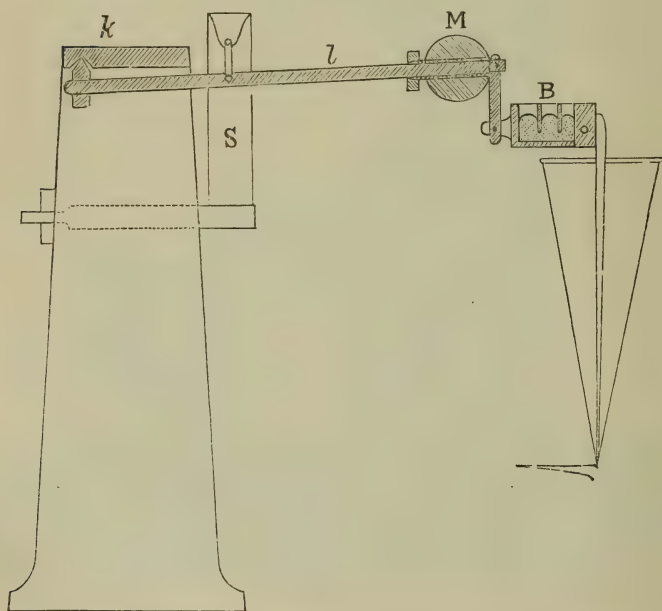
Fig. 2.—*Diagram of Pendulum-Seismograph recording horizontal movements.*



of cylinders of lead, P, supported from their centre of gravity by means of a strong silk thread, which is suspended from a point which can be moved by a simple screw arrangement in either direction, horizontally

or vertically. The pendulum, P, is kept deflected by means of a light brass tube, which passes through its centre in a direction at right angles to its axis, and which carries at one end a vertical knife-edge, and at the other end a very light index of aluminium foil. This thin tube rests with its knife-edge in a flat V-groove, which is fixed to the supporting column, C; and by sliding it more or less through the tube, a greater or less deflection can be given to the pendulum. The other pendulum is exactly similar to P, with the exception that the aluminium index is fixed at right angles to the tube and close to the knife-edge. By this arrangement the two pointers can be adjusted to lie in the same horizontal plane, and in parallel directions. When so adjusted, the planes of deflection of the pendulums are at right angles to each other. The point of suspension is adjusted to be a little in front of, but very nearly vertically above the knife-edge, so that the period of free vibration of the pendulum round a vertical axis is long, compared with the period of vibration of the earth. The vertical component is recorded by means of a compensated spring seismograph (see Phil. Mag. Sept. 1881), which consists of a mass M (figs. 1 & 3) attached near one end of a horizontal lever  $l$ ,

Fig. 3.—Diagram of Spring-Seismograph recording vertical movements.

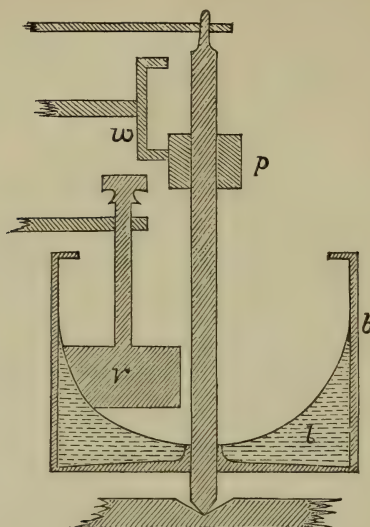


which turns freely round a knife-edge at  $k$ , and is supported by the flat springs S, which are attached to the lever by links working on knife-edges. To the free end of the lever one end of a small box,

B, is hung, the other end of the box being fixed to a horizontal axis. This box is partly filled with mercury for the purpose of compensating by its negative stability the positive stability of the spring. The mode of carrying the mass on the end of a lever is adopted in these instruments because the period of free vibration can by this means be made moderately long with a short spring, thus rendering the instrument more compact and easily compensated. To the front of the box B, a very light vertical index is attached. This index is made of a very thin tube of aluminium supported by angle ties of silk thread so as to give stiffness. The threads are kept tight by a spring which presses against the top of the tube.

The three indexes of the instruments just described rest with their outer ends against the surface of the drum D, covered with smoked paper, the points being arranged in the same straight line parallel to the axis of the drum. When the earth, to which the heavy cast-iron sole plate and supporting pillars are rigidly attached, moves in a direction at right angles to the line joining the knife-edge and the centre of inertia of the masses P and M of the respective instruments, they remain behind in virtue of their inertia, and thus the indices are made to move across the drum in a direction at right angles to that in which it is kept moving by the train of clockwork W. The distance moved by the points of the indices, combined with the known multiplication of the instrument, is sufficient to indicate the direction of the motion, while the shape of the curves traced on the paper and the distances between them indicate the nature and period of the motion, the rate of motion of the drum being known. The drum D is driven by a clockwork train of such length that a fall of the driving weight of one foot is sufficient to keep the drum going at the rate of one turn in two minutes for twenty-four hours. This train of clockwork is actuated by two separate driving wheels, one on each side of the first pinion, so as to avoid at the same time excessive pressure on the bearings of the driving wheels and any great pressure on the bearings of the pinion wheel. It is governed by a continuous-motion governor, which will be understood from fig. 4, in which *b* is a cylindrical brass box mounted on a vertical axis of hard steel running at its lower and upper ends in jewelled bearings. The box is connected to the clockwork through the pinion *p* and the crown wheel *w*. A small quantity of liquid, *l*, is poured into the box; and this, when the box is made to revolve rapidly, forms into a paraboloid of revolution. When the liquid reaches a certain height dependent on the speed required, it comes into contact with a fixed vane *v*, which checks the motion of the box and keeps it going at a uniform rate. It is intended to keep the clockwork continuously in motion, so that when an earthquake takes place it is ready to receive the record. The duration of the shock is then to be reckoned from the length of the record.

The time of occurrence of the shock is determined by a modified form of the apparatus described in the 'Philosophical Magazine' for Nov. 1881, p. 363, and called a "time-taker." The earthquake causes a very delicate circuit-closing apparatus (see 'Philosophical

Fig. 4.—*Diagram of Continuous-motion Governor.*

Magazine' Nov. 1881, p. 358) to close an electric circuit which, actuating electromagnets, causes a mark to be made on the drum D, and at the same time the dial of the time-keeper T to move suddenly forward against ink-pads fixed to the ends of the hands. In this way the hour, minute, and second at which the mark was made on the drum D is recorded; and this, combined with the record of the motion which is being written on the drum, is sufficient to determine the time at which any particularly prominent feature of the shock took place.

The instruments just described have been made to suit the earthquakes which are commonly experienced in Japan, and are consequently not adapted for use where the displacement of the earth is great. A similar set of apparatus could, however, be made to record earthquakes of considerable magnitude. The utility of having such records of earthquakes will be readily admitted; and I should call special attention to the great value of the combination of the record of the time of the occurrence with that of the motions. When the time of occurrence of any of the chief features of the shock is known for a number of places, it becomes a comparatively easy problem to determine the origin of the shock and its rate of propagation. It has been the usual practice in earthquake-observations, to take an approximate measurement of the magnitude and direction of the movement at any place and to deduce angles of emergence and direction of propagation. Now it is hardly necessary to point out that the direction of movement at any point is very much influenced by the presence or absence of surface undulations, and of refractions and reflections from strata of different elastic moduli. I am of opinion that the



direction of motion at any one point cannot be taken as giving at all reliable evidence of the direction of propagation of the shock.

#### DISCUSSION.

The Rev. E. HILL remarked that it was desirable that observations of this kind should be made in this and other countries in which only small earthquake-movements take place. He called attention to the necessity of distinguishing the motions directly due to the shock from the subsequent swinging of the pendulum.

Prof. JUDD asked if arrangements were made in this instrument for recording several earthquakes in succession.

Prof. HUGHES asked whether the instrument had been tried alongside of others differently constructed, and whether the results obtained were the same. It seemed more complicated than the instruments used in the Vesuvius Observatory; and he would be glad if Mr. Gray would explain the advantages of his arrangement for dipping the metal point in the mercury over that adopted by Palmieri, in which the weight carrying the point is simply suspended by a spiral spring attached to the solid framework.

The AUTHOR, in reply, stated that the swing of the pendulum was of such a long period, as compared with that due to the earthquake, that they could not be confounded with one another. The instrument would record any movements between  $\frac{1}{250}$  of an inch and  $\frac{1}{3}$  of an inch; the multiplication might be varied from 4 to 7. No provision was made for the occurrence of more than one earthquake in the same night; but such repetitions of earthquake-shocks were rare in Japan. The instrument had not yet been employed anywhere in its present combination. In reply to Mr. Evans he stated that an instrument of this kind would cost about £45.

16. *On the RELATION of the so-called "NORTHAMPTON SAND" of NORTH OXON to the CLYPEUS-GRIT.* By EDWIN A. WALFORD, Esq., F.G.S. (Read February 21, 1883.)

THE diverse lithological conditions of the deposits in the three great sea-basins of the Bajocian period, the Anglo-Norman, the Cotteswold, and that of the north-eastern counties, have for a long time engaged the attention of geologists in the correlation of their various subdivisions. The Anglo-Norman basin, however, with the rich molluscan fauna of its marly limestones, will not come within the scope of the present paper. It is to that border-land where the estuarine character of the deposits of the northern area becomes merged and lost in the marine strata of the Cotteswold type that I wish more particularly to direct your attention. The greater part of this section of the Midlands, North Oxfordshire, is embraced in sheet 45 N.W. of the Geological Survey.

It may perhaps be worth while to pause for a few moments to review the present subdivisions of the Inferior Oolite. Resting upon the sands for which Mr. Witchell has appropriately suggested the name of the Cotteswold Sands, and which, throughout the Cotteswold area, cover the Upper Lias Clay, are the well-known pisolitic beds of the *Murchisonæ*-zone. They are exceedingly local in their range, and are soon overlapped by the succeeding Lower Freestone beds. These find their equivalents, according to Prof. Judd and Mr. Sharp, in the lower part of the sandy beds of the Midlands known as the Northampton Sands, and northwards in the equally well-known Dogger of the Yorkshire coast. The succeeding Cotteswold stage, the Oolite Marl of the *Sowerbyi*-zone, passes from its marly character in the north to that of a Nerinæan and coralline limestone southwards, and, much reduced in thickness, courses through Dorsetshire to the coast. A part of this Oolitic sea, as I shall presently show, stretched into North Oxfordshire; and in the appearance of the Lincolnshire Limestone near Kettering the continuance of the northern deposits of the period has been indicated, whilst in Yorkshire the Millepore beds present a fauna so analogous as to allow of easy correlation. The freestones of the next higher or *Humphresianus*-zone are confined to the south-western area, and though for the most part very barren, are in the Anglo-Norman area of Dorset rich in a remarkable molluscan fauna. In Yorkshire the Grey Limestones of Scarborough have been referred to this horizon. The zone of *Amm. Parkinsoni* which follows, though much better developed in the north-east Cotteswold region, is yet readily to be traced throughout Dorset and the south-west Cotteswolds. It extends into North Oxfordshire under that condition known as the Clypeus-grit with associated strata, which it will be my endeavour to describe. In Yorkshire Mr. Hudleston finds no evidence of this zone, and is disposed to believe that both it and the Great

Oolite may be represented in time by the Upper Estuarine series locally known as Upper Shale and Sandstone.

*The Cotteswolds.*—As one travels eastwards from the neighbourhood of Cheltenham, the gradual attenuation of the lower Bajocian deposits of the Cotteswolds, so well illustrated in the works of Drs. Lycett, Wright, Holl, and Professor Hull, is admirably shown in the sections exposed in the new Banbury and Cheltenham Railway. One immediately loses sight of the Pea-Grits of Leckhampton Hill; and though at Notgrove station the Oolite Marl is well represented and fossiliferous, yet two miles nearer Bourton-on-the-Water only a thin seam of marl containing old and separated valves of *Terebratula fimbria*, and a few feet of very oolitic limestones of doubtful relationship, are to be seen beneath the bored bed at the top of the Upper Freestones. Old specimens of *T. fimbria* also occur in a hillside freestone quarry on the road from Bourton to Eyeford, though no trace of the marl is there apparent.

At Bourton the rocks are strangely broken; and in the railway-section nearest the station, tumbled masses of Clypeus-grit are to be seen resting upon the Upper Lias with the intervention of merely a few feet of (crinoidal) limestone and sand. The Clypeus-grit shows thereabouts no trace of that attenuation which characterizes the lower horizons of the Inferior Oolite—a fact well illustrated in a section about  $1\frac{1}{2}$  mile east of Notgrove, where I have made the following measurements:—

	ft.	in.
Clypeus-grit, a rubbly brown oolitic limestone with <i>Homomya gibbosa</i> , <i>Amm. Parkinsoni</i> , <i>Ter. globata</i> , &c.; top not shown .....	36	0
Freestone bored by Annelida; base not shown.....	7	0

It will be worth while here also to note an interesting development of sandy limestones between the Clypeus-grit and the Fuller's Earth. These are shown in a cutting about midway between Bourton and Notgrove, east of the Harford-road Bridge.

	ft.	in.
1. Humus .....	1	0
2. Fuller's Earth, yellow and blue clays with a thin rock-bed .....	20	0
3. Red sand derived from decomposition of No. 4.	1	2
4. Reddish sandy limestone with plant-remains...	6	6
5. Dark blue clay with ferruginous stains and plant-remains.....	1	0
6. Rubbly oolite (Clypeus-grit) with <i>Clypeus Plottii</i> , <i>Anabacia</i> , &c.; base not shown.....	5	0

At the base of the Fuller's Earth a course of waterworn limestone nodules, often coated with *Serpulæ*, yield *Trigonia producta*, *Terebratula globata*, *Nerinea* sp. and corals.

Near Stow-on-the-Wold the lower beds of the *Parkinsoni*-zone rest upon a bed of freestone containing numerous joints of Penta-crinites, fragments of Echinoderms, and Polyzoa of the genera

*Spiropora* and *Apseudesia*. A similar bed can be seen at the base of the tumbled oolites of the *Parkinsoni*-stage near Bourton.

Upon crossing the vale of Moreton and reaching the neighbourhood of Chipping Norton one finds the ragstones, in some localities approaching the *Pholadomya*-grit of Dr. Lycett\*, resting boldly upon the thin beds of the Upper Lias. In a brickyard at Salford the unconformability between the two formations is well marked, and the remains of an interposed fine-grained freestone bed are to be seen.

*N. E. Counties.*—As in the marine strata of the west there is thinning-out of the beds in their north-east course, so in the south-west range of the Upper Estuarine series and the Lincolnshire Limestone there is constant diminution of thickness. The disappearance of the latter has been noted at Geddington, north-east of Northampton, by the late Mr. S. Sharp in his excellent paper on the Oolites of Northamptonshire. The "Northampton-sand" series, as may be seen by reference to Prof. Judd's tables†, diminishes in thickness towards Northampton, where, however, it again acquires a great development only to thin away again in its south-west course towards Oxfordshire.

*North Oxfordshire.*—Mr. Hudleston writes‡ "Under the term 'Northampton Sand' are included in North Oxfordshire the whole mass of variable sandy strata (passing at some points into imperfect ironstones, and at others into impure limestones) which intervene between the Upper Lias Clay and the marly limestones of the Upper Zone of the Great Oolite. Such an essentially provisional arrangement may suit in some places; but at Chipping Norton it is certainly liable to mislead, as we have the conventional namesake of the true Northampton Sand, which at Northampton comprises the zones of *A. Murchisonæ* and *A. opalinus*, superposed on the *Clypeus*-grit or *A. Parkinsoni* zone—in other words the Inferior Oolite is turned upside down."

The coming together in the Inferior- and Great-Oolite systems of beds somewhat similar in lithological composition has been a frequent source of perplexity to the officers of the Geological Survey.

In the north-east corner of the map previously mentioned is situated the town of Banbury, flanked eastward by the valley of the Cherwell. To the extreme south-west lies Chipping Norton, west and north-west of which stretches the vale of Moreton with its easterly boundary of the oolitic outliers of Tysoe Hill, Brailes Hill, Long Compton Hill, and the Addlestrop and Rollright plateaux.

Before passing on to the description of the area, which in great part seems to be covered by beds ranging higher in the Inferior-Oolite system, it will be well to pay attention for a short time to a somewhat abnormal series of oolitic limestones at Coombe Hill, about 5 miles south of Banbury. The beds, the remains of which were formerly worked at Blackingrove, on the opposite side of the valley to Coombe Hill, have been let down by a fault. The following is a section:—

\* Cotteswold Hills, p. 68.

† Geol. Rutland, pl. 1.

‡ Proc. Geol. Assoc. vol. v. p. 383.



	ft.	in.
No. 1. Humus.....	1	0
2. Sandy oolitic limestone rubble.....	3	6
3. Oolitic limestone with black shining concretions.....	3	10
4. Sandy marl.....	1½ to	2
5. Oolitic limestone with black concretions and limestone pebbles.....	2	0
6. Friable oolitic very shelly marl, with masses of worn corals, sponges, (?) <i>Lima pectiniformis</i> , <i>Terebratula submaxillata</i> , <i>Serpula socialis</i> , &c.		7
7. Shelly oolitic limestone; base not shown .....	1	0

Professor Judd, in the admirable introductory essay to his 'Geology of Rutland' has briefly described the beds, and has given a list of fossils from the collections of Mr. T. Beesley, F.C.S., and the Survey. This list I have fortunately been able to supplement with a few species, see Table A (p. 239).

Amongst the common fossils are *Natica cincta* (*leckhamptonensis*), *Terebratula submaxillata*, *Serpula socialis*, and *Ostrea Marshii*.

Amongst the Polyzoa occur species of *Apeudesia*, *Diastopora*, *Tubulipora*, and *Stomatopora*, whilst the Millepore *Spiropora straminea* is not uncommon. In the 'Geological Magazine' for May 1882, Mr. Hudleston has shown *Natica cincta* to be a characteristic shell of the zone of *Ammonites Sowerbyi*, not only in the Millepore-beds of Yorkshire, but also in the Oolite Marl of the Cotteswolds. The occurrence in Oxfordshire of this shell with the Polyzoa so frequently found in this horizon adds to its right to be so considered; and hence we may infer that we have a local development of a zone hitherto unrecognized in our area. Perhaps, however, Professor Judd may have included this phase as a subzone of *Ammonites Murchisonæ*. The Ammonites are unfortunately so badly preserved as to furnish little additional evidence. The numerous corals, the bulk of which are rolled and waterworn, show the coralline conditions of this oolitic sea. The characteristic Brachiopoda, with the exception of one doubtful specimen of *Terebratula fimbria* in Mr. Beesley's collection, are absent. *Terebratula submaxillata*, however, is abundant\*.

*Banbury and Hook-Norton type*.—In the immediate neighbourhood of Banbury a few sand-capped hills and an outlier preserved by a fault alone testify to the former extension of beds of the Bajocian series over the locality. Nine miles north-west of the town a small patch of sand occurs on the crest of one of the picturesque hills of Burton Dassett, marking, so far as we can ascertain, the limit in that direction; whilst north-eastwards the ridges of Byfield, Red Hill, and Thorpe Mandeville border the more extended deposits of Northamptonshire.

\* By the kind courtesy of Prof. Prestwich, F.R.S., I have been enabled to examine collections from Blockley, made by Mr. S. Stutterd and now in the Oxford University Museum. A fauna almost identical with that of Coombe Hill, including even *Natica cincta*, is shown, associated with characteristic forms of the Oolite Marl, such as *Terebratula fimbria*, *Waldheimia carinata*, and *Rhynchonella subboleta*.

At the Constitution-Hill section near Banbury all that remains of the Inferior Oolite is from twelve to twenty feet of white and fawn-coloured sands with occasionally bands of stone containing such fossils as are here quoted, associated with numerous plant-remains. Between it and the Great Oolite above, both of which have been let down by a fault, a thin stratum of black clay intervenes.

Pycnodus.	Pecten articulatus.
Trigonia v-costata.	Avicula braamburiensis.
—— conjungens.	Ostrea gregaria.
Tancredia axiniformis.	——, sp.
Corbicella bathonica.	Diastopora.
Astarte, sp.	Serpula filaria.
Cardium, sp.	Montlivaltia lens.
Gresslya abducta.	Annulated Algæ.

The type of deposits of the district N. and E. of Banbury is very similar—sands, often ferruginous, with occasional courses of shelly limestone towards the base. These rest upon and pass into the clays of the Upper Lias, without, so far as I have seen, any appearance of unconformability other than in the marked change of life. South-westward the same conditions prevail. Over the high lands from Tadmarton Camp to Hook Norton stretches a series of beds of sand and sandy limestones, below which follow courses of brownish crystalline limestone containing *Montlivaltia lens*, *Pecten demissus*, *P. personatus* and *P. lens*, and rolled stones covered with *Serpulæ* and Polyzoa. From the sandy beds were obtained annulated stems of Algæ; and by the Rev. P. B. Brodie a pretty new species of *Trigonia*, described by Dr. Lycett, in his monograph of the British *Trigoniæ*, under the name of *Trigonia Brodiei*, was got from the limestones which appear to represent the base of the Inferior Oolite.

The sequence of the beds may be noted in passing up the Milcombe Hill towards the Camp, a fine specimen of a Romano-British earthwork. The road-cutting exposes the Upper Lias clays; and further on a small limestone-quarry yields, though sparingly, the fossils mentioned. The overlying sands are shown best in the sand-pits on Tadmarton Heath at the top of the hill. Other, though sparingly fossiliferous, sections, where courses of hard limestone come in between the sandy beds, may be seen near the Gate Inn, Hook Norton, by the roadside south of Sibford Ferris, and near the Temple Mill. The whole of these beds, hitherto termed "Northampton Sand," are included under that phase of the Inferior Oolite marked in the Survey map 5' g 7'; and this same 5' g 7' also includes the lower zone of the Great Oolite of this district.

The new railway-cutting about half a mile south of Hook Norton has fortunately supplied a section (fig. 1) so complete that we may take it for our type in attempting the correlation of other beds of the district. The hill has been but partially worked through, the cutting on its north side being the longer and deeper; that on the south side near Duckpool Farm, though shallower, still shows the fossiliferous beds of the Inferior Oolite resting upon the Upper Lias, against which are faulted a series of the Lower Limestones and clays



		ft.	in.
	1. Humus .....		6
	2. Flaggy white oolitic limestone.....	2	0
	3. Sand weathering white.....	3	6
	4. Hard cream-coloured limestone, bored in places at the base by Annelids.....	1	9
E.	5. Brown sand.....	}	with <i>Ostrea calceola</i> 11
	6. Sandy limestone weathering rusty.....		and <i>Lima</i> 4
	7. Sands.....		5
	8. Sandy limestone becoming loose at bottom.....	2	3
	9. Sand.....		1
	10. Sandy limestone.....	1	10
	11. Coarse gritty sand.....		2
	12. Sandy limestone.....	1	3
	13. Sand.....		1
	14. Violet-coloured limestone with plant-remains.....	1	11
	15. Purplish tenacious clay, sandy.....		7
	16. Shelly limestone.....		5
D.	17. Sandy clay.....		2
	18. Hard limestone.....	1	0
	19. Brown sandy limestone, plant-bed.....		4
	20. Purplish marly clay.....		2 $\frac{1}{2}$
	21. Soft marly limestone and clay.....	2	0
	22. Hard cream-coloured limestone with <i>Astarte minima</i> .....	1	0
C.	23. Sand.....		10
	24. Shelly limestone containing <i>Trigonia</i> and corals.....	1	0
B.	25. Sandy flaggy limestone, Ammonite-bed.....		10
A.	26. Sandy and blue-hearted limestone with corals.....	4	6
	27. Red sand.....		3
	28. Upper Lias clay.....		

Fragments of a higher bed than any in the section and representing conditions not previously recognized in Oxfordshire are shown here and there in rifts caused by the flexure or faulting of the Inferior-Oolite Limestones in their dip towards the valley. The fragments consist of a hard marly limestone, through the grey base of which in some parts are scattered oolite grains of a yellowish colour. It is crowded with small Gasteropods of the genera *Cerithium*, *Kilvertia*, *Monodonta*, and *Nerinea*; bivalves are equally prominent, amongst which *Mytilus imbricatus* and small shells of *Astarte* (nov. sp.) predominate. Numerous specimens of a fine coral (*Cryptocænia*) also occur. The fauna is essentially dwarfed in character, and its relationship is with that of the lower zone of the Great Oolite.

From the Lower Limestone bed (No. 26) I have obtained *Lima punctata*, *Avicula Münsteri*, *Rhynchonella cynocephala*, and a probably new species of *Delphinula*. This limestone with the red sand below I have designated series A of the section. The sandy flaggy limestone (B) yields a smooth Ammonite, believed by Mr. Hudleston to be referable to *Ammonites læviusculus*, Sow., as well as *Terebratula perovalis* and *T. submaxillata*, *Myacites Goldfussi*, &c. I have obtained *Trigonia producta* from the worn and oyster-covered surface of bed 24 (C). A coral band at the base yields magnificent specimens of *Clausastræa Conybeari*, *Isastræa serialis* and *limitata*, and *Thamnastrea Defranciana*. The succeeding layer (bed 22 of series C), an oolitic shelly limestone, has yielded the bulk of the species in the



list. The common forms are *Astarte minima*, *Pecten lens*, and *Lucina despecta*, with which occurs more rarely *Rhynchonella spinosa*. A fragment of *Ammonites Parkinsoni* came apparently from this stratum also. The *Trigoniae*, though not numerous individually, array themselves in great force specifically; noticeable amongst them are the bold and beautiful valves of *T. producta*, *T. gemmata*, and the varieties of *T. signata*. Several of the species named evidence a horizon of the Inferior Oolite approaching that of the Trigonia-grit; *Astarte minima* and *Trigonia signata* occur in the Grey Limestone of Scarborough; but *T. producta* seems not to have ranged lower than the Trigonia-grit of Cheltenham and Stroud.

The plant-bed of series D suggests a change of conditions from the decidedly marine and coralline phase of the lower beds. Carbonaceous fragments occur more or less throughout the whole of this series, especially in the limestones Nos. 14 and 19; the fauna, however, is still marine. *Quenstedtia oblita*, again, a species of the higher beds of the Cotteswolds and Yorkshire, occurs in series D, associated with the remains of stems of reed-like plants and wood.

The series E, of sandy limestones passing at times into a bastard freestone, which we have not met with before reaching the Hook-Norton area, covers the greater part of the high lands about Rollright, Long Compton, and Addlestrop. It is capped here and there by coarse oolitic grits hereafter to be described. I have measured sections near Chipping Norton attaining a thickness of 20 feet. Towards the base of this series occurs a sandy limestone crowded with an oyster approaching the *Ostrea calceola* of Quenstedt (*pyxisformis* of Wright), together with numerous specimens of *Lima cardii-formis*.

Table B (pp. 239-242) gives a list of the Hook-Norton fossils.

Between Hook Norton and Swerford, about a quarter of a mile from the latter village, Mr. Bennett's quarry shows a series of the upper beds of the Inferior Oolite which exhibit the passage-beds into the Great Oolite more clearly. It is as follows:—

	ft.	in.
1. Humus .....	1	6
2. Grey clay with white concretions .....	6 in. to	2 0
3. Black clay mingled with fragments of marly limestone, containing <i>Kilvertia</i> , <i>Cerithium</i> , and <i>Lucina</i> , resting unconformably on No. 4		7
4. Grey siliceous crystalline limestone with traces of <i>Nerinea</i> and bivalves .....		11
5. Brown clay .....		1
6. Black sand .....		3
7. Flaggy fawn-coloured sandy limestones and sand .....	4	2
8. Compact light fawn-coloured limestone, base not shown .....	6	0

The pit furnishes the road-metal for the greater part of Swerford parish, and is worked close to the edge of a fault which traverses the country from E. to W. The fragments of grey limestone mingled with the black clay are identical with similar fragments from the top of the Hook-Norton cutting. Out of a fissure towards the lower end of the pit have been extracted some great blocks of travertine-like stone with beautiful surfaces made up of radiating

masses of pale yellow crystals. Several of the blocks were from one to two feet thick and quite pure. That the sequence of the beds below is the same as at Hook Norton can be traced in an old quarry in a garden on the other side of the valley, where the lower limestones have been worked. The fawn-coloured sandy limestones, thereabouts the top beds of the Inferior Oolite, may be seen, in several other sections on the south side of Swerford Park, attaining a thickness of about twenty feet, and often banded with ferruginous stains. At Colls-Coombe barn they are to be seen capped with black clay, which Mr. Hudleston\* has made a boundary-line between the Inferior and Great Oolite beds of the region.

Between South Newington and Wiggington, about half a mile west of the former, a now disused roadside quarry presents conditions slightly varying from the Hook-Norton type, in which *Astarte minima* is rarely associated with plant-remains. It shows:—

	ft.	in.
1. Humus.....	1	0
2. Sandy rubble .....	1	3
3. Flaggy cream-coloured limestone.....	9	
4. Flaggy ferruginous limestones passing into sand .....	1	
5. Sandy limestone, with Cyprinoid shells, passing into sand .....	3	10
6. Dark brown ferruginous limestone, with layers of <i>Astarte minima</i> with plant-remains, <i>Trigonia</i> , &c.....	2	
7. Violet-coloured limestone, sandy at top and harder at base, with black shining concretions and oysters .....	1	4
8. Limestone in two courses with blue centres .....	4	9

A fault crosses the quarry from E. to W., bringing down a mass of fawn-coloured sands with the ordinary black-clay capping.

On ascending the Otley Hill, two miles and a half north-west by west from Hook Norton, one notes in the fine panorama of Midland scenery the high plateau of Tadmarton throwing off, on its northern flank, the tributaries of the Stour to flow westward, whilst from the base of the ridge on which one stands the stream springs to join the Swere, which meanders in its journey to the valley of the Cherwell round the knolls crested with the villages of Wiggington, South Newington, and the Barfords. The rich red colour of the arable lands of the Middle-Lias marlstone lies in pleasant contrast about the green slopes of the Lias vales. Near the top of the hill, and in a small quarry by the side of the road leading to Traitor's Ford, some fossiliferous beds are to be seen, the equivalent of series B and C of the Hook-Norton cutting, mingled with the remains of an apparently lower horizon. Prof. Judd has described the section† and has given a list of the fossils, which I quote with additions by Mr. Windoes and myself. See Table C (p. 242).

One is confronted here by the difficulty of an apparent admixture of forms supposed to be restricted to both high and low Cotteswold horizons. The former is evidenced by *Trigonia signata* and *T. producta*, and the *Terebratula globata* of Prof. Judd's lists; the latter

\* Rep. Geol. Assoc. vol. v. no. 7, p. 3.

† Geol. Rutland, p. 21.

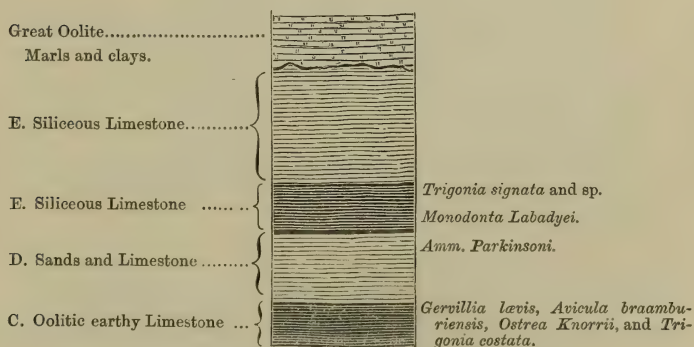
by separated valves of *Rhynchonella cynocephala* from my own cabinet, and *Terebratulula simplex* from that of Mr. T. J. Slatter, F.G.S. It would appear as if there are here some remains of beds of a lower zone, or of material derived from them, though the section is unfortunately so small as not to allow satisfactory determination. The fauna of series B and C of Hook Norton is very similar, excepting, however, the last-named species.

A little higher up the hill a sand-pit exposes the plant-beds, D; and in the roadside quarries nearer Great Rollright the ridge is crested with beds of sandy siliceous limestones representing series E. Attention must here be called to the fact that at the north end of the ridge called Otley Hill, immediately above the Upper Lias, is the outcrop of the so-called "Northampton Sands" (Hook-Norton type), whilst two miles further south-westward, on the north and south flanks of the part called Bright Hill, whereon stands the well-known circle of the Rollright stones, crops out the Clypeus-Grit (Cotteswold type), richly stored with its characteristic fossils and resting also upon the Upper Lias.

At Whichford, about two miles west of Otley Hill, a roadside quarry yields *Astarte elegans* &c. At the Grayton pit, further up the hill, the higher beds are extensively worked, and a stratum abounding with separated valves of *Trigonia signata* can be clearly traced. The section as measured is:—

	ft.	in.
1. Humus .....	1	0
2. Cream-coloured siliceous limestone .....	6	6
3. Sandy limestone with <i>T. signata</i> , passing into No. 4 .....	10	
4. Blue-hearted limestones, with wood; base not shown.....	3	0

Fig. 2.—Vertical Diagram Section, Sharpshill,  $1\frac{1}{2}$  mile N. of Otley Hill. (Scale 1 : 144.)



*Chipping Norton*.—Upon taking to the Chipping-Norton road and descending the hill to the Dip valley, one notes, in the fields to the north-west of Langdon Bridge, the outburst of springs marking the

top of the Upper Lias, whilst the banks above the stream are strewn with fragments and ordinary fossils of the Clypeus-grit, with which are pieces of limestone conglomerate, containing *Montlivaltia lens* and *Pecten personatus*, together with compact and sandy limestones, with *Mytilus Sowerbyanus*, *Avicula Münsteri*, &c., forms common to the lower beds of the Hook-Norton area. *Pecten personatus* occurs abundantly at the base of the *Parkinsoni*-zone near Notgrove. Superimposed beds of the fawn-coloured oolitic sandy limestones can be traced in the crest of the slope, in the roadside quarries, and in the quarry on the Bright-Hill road. A fault crossing the district from N.E. to S.W. has fortunately caused the preservation of the higher beds which the railway has intersected. A detailed section has been given by Mr. Beesley\*, and a summarized section by Mr. Hudleston†. In the railway-cutting the fawn-coloured limestones (E) are shown in the excavation for the piers of the bridge, covered elsewhere by 8 feet of hard crystalline limestone-grits, composed of rolled fragments of shells and spines of Echinoderms, quartz, and oolitic grains, but containing few recognizable fossils. Upon these rests a bed of whitish, compact, fine-grained mortar-like limestone, with shells in very indifferent preservation and a few plant-remains. Mr. Beesley, prior, however, to the discovery of any recognizable fossils, suggested its affinity with the Lincolnshire Limestone, supposing it to be inferior to the Clypeus-grit, which appears hereabouts to be at the base of the Inferior Oolite of this district. Fortunately, since Mr. Beesley's paper was written, the diligent work of Mr. J. Windoes has been rewarded by the accumulation of the following fossils, to which I have been able to add a few species. Those marked ‡ are from the gritty limestones (Chipping-Norton limestones), the others from the mortar-like bed.

Saurian tooth.	†Leda, sp.
Nerinaea Eudesii, M. & L.	†Opis similis, Sow.
†Nerinaea, smooth sp.	†Lima cardiiformis, Sow.
†Nerinaea.	†Avicula costata, Sow.
Nerinaea, several forms.	Astarte.
†Nerita rugosa, M. & L.	†Placunopsis socialis, M. & L.
Turbo paludinaeformis.	†Pentacrinites.
Turbo, small sp.	†Spines of Cidaris.
Solarium, small sp.	†Acrosalenia.
Cerithium limæforme?, Röm.	†Plates of Starfish.
†Pleurotomaria, nov. sp.	Plant-remains.
†Actæonina, several forms.	

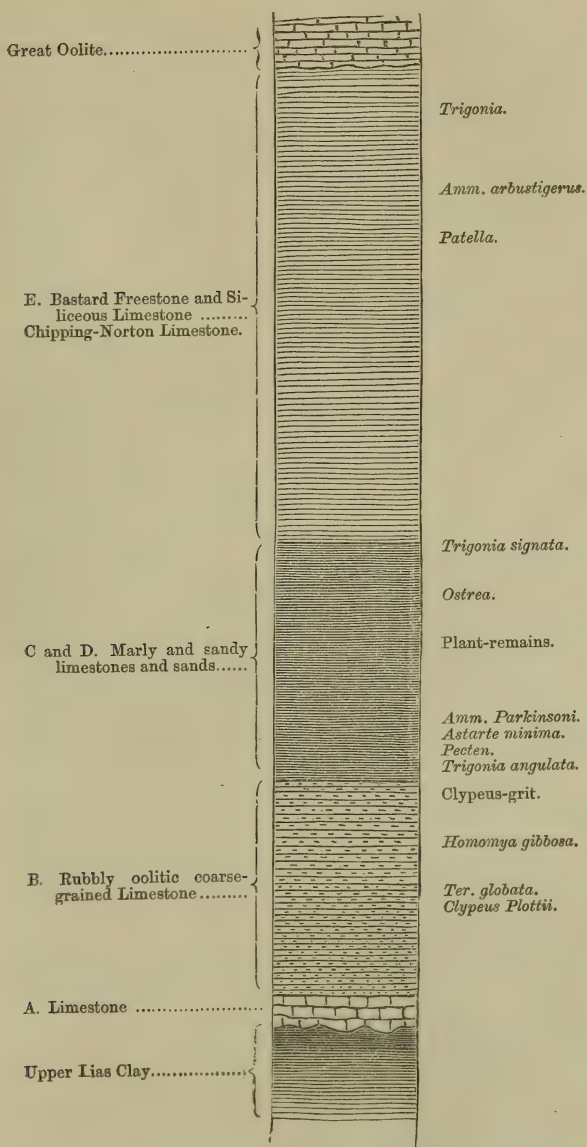
Immediately below the black clay, the base of the Great Oolite, is a layer of red and black sand with occasionally blocks of travertine-like stone, which I have noted as occupying a similar position at Swerford and also around the slope of Bright Hill towards Long Compton. These are suggestive of great waste towards the close of the Bajocian period; for, capped as the blocks are with marls and

\* Proc. Geol. Assoc. vol. v. p. 15.

† Ibid. p. 3.



Fig. 3.—*Generalized Vertical Section, Chipping Norton.*  
(Scale 1 : 144.)



clays, it would be difficult to imagine them to have been formed subsequently to the deposition of the impervious layers.

About half a mile south of Langton Bridge, at the Cross Roads, the Clypeus-grit, with its characteristic fossils, *C. Plottii*, *Terebratula globata*, &c., may be noted in the road-cutting. Its junction with the Upper Lias is apparent by the growth of coarser grass and rushes. The walls by the roadside are built of the ragstone abounding in the fossils mentioned. Resting upon the grit may be seen a few feet of sandy limestones of the lower Hook-Norton type, the probable equivalents of C and D. In stacks of stone by the roadside, derived from the banks, I have noted the following fossils:—*Pecten articulatus*, *Trigonia producta*, *Astarte minima*, *Myacites Goldfussi*, *Perna mytiloides*, and plant-remains. These pass into sandy limestones, with abundant carbonaceous fragments, containing *Trigonia signata*, which in turn are covered by the siliceous oolites of which sections may be seen near. To Mr. Windoes, of Chipping Norton, must be assigned the credit of having first noted the sequence of the beds of this interesting cutting. The beautiful species of *Trigonia* mentioned characterizes such horizons as the Upper *Trigonia*-grit of the Cotteswolds and the Grey Limestone of Yorkshire. It is found also, occasionally in abundance, in a quarry near the Priory Farm. Many years since, it was collected in large numbers by my friend Mr. Stutterd from a pit between Rollright and Hook Norton, where now, however, it is rarely to be found. The fossil is associated with an oyster, perhaps *Ostrea calceola*, Quenst., and *Lima cardiiformis*. Some of the specimens from this region show a singular variation in the area; the upper part has solid rib-like costellæ in the place of the two fine costellæ which ordinarily proceed from the marginal nodule. The median row of tubercles has vanished, and the line is shown by the inflexion of the thick V-shaped costellæ\*. The late Dr. Lycett was engaged in describing the Oxfordshire varieties of *T. signata*, with several new species, for a supplement to his beautiful monograph on the British *Trigoniæ*, prior to the illness which deprived us of the aid of so skilful a palæontologist.

The siliceous oolites which cover the whole of the Chipping-Norton area, and which we have noted as covering the bed with *Trigonia signata*, have been called by Mr. Hudleston the Chipping-Norton Limestone. It is probable that they attain a thickness of 30 feet, though not more than 14 feet of these beds are seen in Mr. Hudleston's type section, the *Ceteosaurus*-quarry.

Resting upon this limestone at Pomfret Castle, on the Banbury road, is a bed of tough ragstone, from 1 to 2 feet in thickness, crowded with casts of costate and clavellate *Trigoniæ*. The same bed made its appearance also at the Park-corner quarry, now closed up, about one mile north of Chipping Norton. Blocks, probably transported, can be seen also in some disused stone-pits in Heythrop Park. Mr. Windoes states that during some excavations for the Chipping-

\* The *Trigonia signata* from the lower part of series C of Hook Norton is similar to the form found at Cold Comfort, near Cheltenham. Those from higher beds near Rollright are more truncated posteriorly.

Norton water-works, he saw this bed covered by yellow clays containing an abundance of *Ostrea acuminata*.

The Inferior Oolite of Sheet 45 N.W., mapped by the Geological Survey as 5' g 7', and in part hitherto termed the "Northampton Sand" of North Oxfordshire (C, D, and E of my section), may be divided into (1) the marine and estuarine limestones of the Hook-Norton type, (2) the *Trigonia-signata* bed, and (3) the Chipping-Norton Limestone, which embraces all between the "*signata*" bed and the Great Oolite. The greater part of the limestones of the Hook-Norton type have been shown to overlie the Clypeus-grit at the Cross Roads near Over Norton and in the Dip valley near Langdon Bridge, and hence to the base of the Chipping-Norton limestone, at least, to be well within the zone of *Ammonites Parkinsoni*. Well-sinkings have been noted at Chipping Norton by Mr. Windoes, yielding the characteristic fossils of the Hook-Norton limestones, before the Clypeus-grit was reached. Whether the Chipping-Norton limestones can be assigned to the *Parkinsoni* zone is somewhat doubtful; for, with the exception of a large *Patella* and an Ammonite which appears to be *Amm. bullatus*, D'Orb., recognizable fossils seem not yet to have been found. Certainly in the mortar-like beds of the Dip valley (Langdon Bridge), if not in the limestones below, there is the dawn of a Bathonian fauna not so distinct in its facies from the remains of the Great-Oolite beds above as from that of the Inferior-Oolite beds beneath. In part, perhaps, the equivalent of these beds above the Clypeus-grit may be found in the white oolite above the Clypeus-grit of Mr. Witchell's Stroud-hill section\*, and in those beds constituting the Inferior Bathonian of the Côte-d'Or described by M. Jules Martin†.

It will be remembered also that in the section quoted between Notgrove and Bourton-on-the-Water sandy limestones with *Trigonia*, and a clay-bed with plant-remains, intervene between the top of the Clypeus-grit and the base of the Fuller's Earth. The base of the Fuller's Earth in that section I have found to be full of water-worn stones incrustated with *Serpulæ*, rolled corals, numerous fragments of *Trigonia* (including a fairly preserved *Trigonia producta* of the Oxfordshire type), *Nerinea*, and *Terebratula*. These appear to be the representatives of beds which I have shown to attain no inconsiderable development eastwards.

If, as seems to be probable, the Oxfordshire equivalents of these beds *underlie* the Fuller's Earth, they should belong to the Inferior Oolite, notwithstanding an incoming of Bathonian fossils. However, *Ammonites bullatus* in the Chipping-Norton limestone has a Bathonian look.

Dr. Wright, in speaking of the eastern phase of the Clypeus-grit, states that "it is not, as it has been figured and described by some

\* "Notes on a section of Stroud Hill," by E. Witchell, Esq., F.G.S. (Proc. Cotteswold Field Club.)

† Descr. du Groupe Bathonien dans la Côte-d'Or, par M. Jules Martin.

authors, *a bed superior to the Upper Trigonía-grit of Leckhampton\**, but is in fact the equivalent of the Lower *Trigonía*-bed." The analysis of the table of fossils of the Hook-Norton limestone (C) inclines towards an agreement with the fauna of the zone of *Ammonites Parkinsoni*. The affinity between the Clypeus-grit and series C and D of Hook Norton is illustrated by the occurrence in both of *Trigonía producta* and *Am. Parkinsoni*, as well as of such cosmopolitan forms as *Pecten personatus*, *Myacites Goldfussi*, and *Pholadomya Herculiti*. Another link in the chain of evidence is that *Trigonía signata* has not been found in the Clypeus-grit of North Oxfordshire, but appears sparsely in the Hook-Norton Limestone, and attains its maximum and dies out in the "*signata*" bed, into which the Hook-Norton limestones probably merge. A noticeable feature, however, is the restriction to the former bed of such abundant species as *Homomya gibbosa* and *Clypeus Plottii*, neither of which appears to have been found in either Hook-Norton or Chipping-Norton limestones, though the passage of the latter species is demonstrated by its appearance in the lower beds of the Great Oolite. *Terebratula globata*, quoted by Prof. Judd from Otley Hill, I have recognized doubtfully in a solitary specimen from Hook Norton.

It appears as if this area, during the Lower Jurassic period, formed a barrier which prevented the sea of the Clypeus-grit from extending into the north-east area, but was surmounted by the later overflow of seas affected by the estuaries of the north-east; and so the Echinoderms and Mollusca which characterize the grit died out or migrated, being unable to adapt themselves to the new conditions. The sea would seem to have receded after the deposition of the early oolitic beds only to return after the filling up of the greater part of the Cotteswold basin. There is evidence of considerable denudation after the deposition of certain of the Lower Bajocian beds and prior to the time of the Clypeus-grit, and again at about the commencement of the Great-Oolite period. The former is shown in the before-mentioned section at Salford, where the Clypeus-grit can be seen resting unconformably upon the Upper Lias, with the intervention here and there of the remains of a compact freestone-bed covered by a thin ferruginous band. The records of the second period are evident wherever the junction of the Inferior with Great Oolite is shown. At Sharpshill (fig. 2), Swerford, and Newbottle it is especially marked.

Of the subsequent denudation by which the hills of North Oxfordshire were in so many cases partially, if not wholly, stripped of their limestone caps, and by which the soft outlines of the placid scenery of the Midlands were sculptured, nothing need here be said.

\* "On the Subdivisions of the Inf. Oolite of the S. of England," by Dr. Wright, F.R.S. (Quart. Journ. Geol. Soc. vol. xvi. p. 43).



TABLE A.—*Fossils from Coombe Hill, Oxfordshire.*

Strophodus.	Hinnites abjectus, <i>Phil.</i>
Acrodus.	Perna rugosa, var. quadrata, <i>M. &amp; L.</i>
* Ammonites Murchisonæ, <i>Sow.</i>	Gervillia pernoides, <i>Desl.</i>
—, sp., cast.	Harpax, sp.
Nautilus.	Ostrea flabelloides, <i>Sow.</i>
Belemnites ellipticus, <i>Mill.</i>	* —, var.
Natica cincta, <i>Phill.</i>	* Terebratula globata, <i>Sow.</i>
Patella rugosa, <i>Sow.</i>	* — perovalis, <i>Sow.</i>
Chemnitzia ?; very large sp.	* — Phillipsi, <i>Sow.</i>
* Nerinea Jonesii, <i>Lyc.</i>	* — fimbria, <i>Sow.</i>
—, sp.	* — plicata, <i>Buckm.</i>
* Phasianella striata, <i>Sow.</i>	— submaxillata, <i>Mor.</i>
Cerithium limæforme, <i>Röm.</i>	Rhynchonella, sp.
* Pleurotomaria ornata, <i>Defr.</i>	Serpula socialis, <i>Goldf.</i>
—, sp.	— convoluta, <i>Goldf.</i>
Cypricardia brevis, <i>Wright.</i>	* —, sp.
Myacites Goldfussi, <i>Ag.</i>	Pentacrinus Milleri, <i>Aust.</i>
Tancredia ?	Pygaster semisulcatus, <i>Phill.</i>
Mytilus imbricatus, <i>Sow.</i>	Stomechinus germinans, <i>Goldf.</i>
— lunularis, <i>Lyc.</i>	Symphyllia Etheridgii, <i>Dunc.</i>
* Arca Prattii, <i>M. &amp; L.</i>	Latomeandra Davidsoni, <i>E. &amp; H.</i>
* —, sp.	Thamnastræa Wrightii, <i>Dunc.</i>
* Myoconcha crassa, <i>Sow.</i>	—, sp.
* Modiola aspera, <i>Sow.</i>	Isastræa limitata, <i>Lamx.</i>
Macrodon Hirsonensis, <i>d'Arch.</i>	Thamnastræa Defranciana, <i>Mich.</i>
* Astarte elegans, <i>Sow.</i>	* —, sp.
Trigonia Beesleyana, <i>Lyc.</i>	* Cladophyllia sp.
— pullus, <i>Sow.</i>	* Montlivaltia trochoides, <i>E. &amp; H.</i>
* Lucina Wrightii, <i>Opp.</i>	* — Delabechii, <i>E. &amp; H.</i>
Lithodomus.	Stylina ?
Lima cardiiformis, <i>M. &amp; L.</i>	Spiropora straminea, <i>Phill.</i>
— pectiniformis, <i>Schl.</i>	Diastopora, cf. margo-punctata,
— ovalis, <i>Schl.</i>	Waagen.
— rodburgensis, <i>Lyc.</i>	— oolitica, <i>Vine.</i>
—, nov. sp.	Tubulipora, sp.
Pecten lens, <i>Sow.</i>	Apseudesia clypeata, <i>Haime.</i>
— arcuatus, <i>Sow.</i>	Proboscina, cf. prorepens, <i>Waagen.</i>
— articulatus, <i>Schl.</i>	—, sp.
* — vimineus, <i>Sow.</i>	Diastopora, sp.
* — annulatus, <i>Sow.</i>	Stomatopora, cf. Waltoni, <i>Haime.</i>
* — personatus, <i>Münst.</i>	

\* From Prof. Judd's list.

TABLE B.—*Fossils from the Inferior Oolite of Hook Norton.*

Saurian Bone .....	A	...	C	...	E
Pycnodus .....	...	...	C	...	...
Belemnites giganteus, <i>Schlot.</i> ...	A	...	C	...	...
— gingensis, <i>Oppel</i> .....	A	...	C	...	...
Ammonites læviuseculus, <i>Sow.</i> ...	...	B	...	...	...
— Parkinsoni, <i>Sow.</i> .....	...	...	C	...	...
Alaria, sp. ....	...	...	C	...	...
Cerithium costigerum, <i>Piette</i> ...	...	...	C	...	...
— exscalptum ?, <i>Lyc.</i> .....	...	...	C	...	...
— near to strangulatum,	...	...	...	...	...
d'Arch. ....	...	...	C	...	...
Chemnitzia vetusta, <i>Phil.</i> .....	...	...	C	...	...
—, sp. ....	...	...	C	...	...
Turbo ornatus, <i>Sow.</i> .....	A	...	...	...	...
— cf. hamptonensis, <i>M. &amp; L.</i> ...	...	...	C	...	...

TABLE B (continued).

Turbo, sp. ....	...	...	C			
Monodonta Labadyei, <i>d'Arch.</i> ...	...	...	C			
— heliciforme, <i>M. &amp; L.</i> ....	...	...	C			
— cf. Lycetti, <i>Whit.</i> ....	...	...	C			
— or Turbo, 4 or 5 sp. ....	...	...	C	...	...	Probably young <i>M. Lylli</i>
— cf. formosa ( <i>M. &amp; L.</i> ) ....	...	...	C			&c.
Pleurotomaria ....	...	...	C			
Trochus monilitectus, <i>Phil.</i> ....	...	...	C			
Amberleya ....	...	...	C			
Delphinula, sp. ....	A					
Nerita ....	...	...	C			
Actæon pullus, <i>Koch.</i> ....	...	...	C			
Dentalium Parkinsoni, <i>Quenst.</i> (entaloides, <i>Lyc.</i> ) ....	...	...	C			
Trigonia producta, <i>Lyc.</i> ....	...	...	C			
— angulata, <i>Lyc.</i> ....	...	...	C			
— —, var. ....	...	...	C			
— signata, <i>Ag.</i> ....	...	...	C			
— —, var. rugulosa ....	...	...	C?			
— —, var. of Zieten ....	...	...	C			
— gemmata, <i>Lyc.</i> ....	...	...	C			
— conjungens, <i>Phill.</i> ....	...	...	C			
— Brodiei, <i>Lyc.</i> ....	...	...	C			
— Moretoni, var. oxoniensis, <i>Lyc.</i> ....	A	...	C			
— costata, <i>Park.</i> ....	...	...	C			
— v-costata, <i>Lyc.</i> ....	...	...	C			
— angulata, <i>Lyc.</i> ....	...	...	C			
— pullus, <i>Sow.</i> ....	...	...	C			
— denticulata, <i>Lyc.</i> ....	...	...	C	...	E	
— —, var. ....	...	...	C			
— duplicata, <i>Lyc.</i> ....	...	...	C			
— nov. sp., <i>Lyc.</i> ....	...	...	C			
Limopsis coliticus, <i>d'Arch.</i> ....	...	...	C			
Astarte minima, <i>Phill.</i> ....	...	...	C			
— rustica, <i>Walton.</i> ....	...	...	C			
— bathonica, <i>Lyc.</i> ....	...	...	C			
— nov. sp. ....	...	...	C	...	...	[depressa,
— interlineata ....	...	...	C	...	...	Like a flattened form of <i>A.</i>
— —, var. ( <i>Lyc.</i> ) ....	...	...	C	...	...	*
Opis, sp. ....	...	...	C	...	...	*
— 3 sp. ....	...	...	C			
Arca Prattii, <i>M. &amp; L.</i> ....	...	...	C			
— minuta, <i>Sow.</i> ....	...	...	C			
Cucullæa concinna, <i>M. &amp; L.</i> ....	...	...	C			
— pulchra, <i>Sow.</i> ....	...	...	C			
— —, sp. ....	...	...	C			
Nucula variabilis, <i>Sow.</i> ....	...	...	C			
Lucina despecta, <i>Phil.</i> ....	...	...	C			
— cf. crassa, <i>Sow.</i> ....	...	...	C			
— striatula?, <i>Buv.</i> ....	...	...	C			
Cardium subtrigonum, <i>M. &amp; L.</i> ...	...	...	C			
Isocardia cordata, <i>Buckm.</i> ....	...	...	C			
— —, sp. ....	...	...	C			
Corbula Buckmani, <i>Lyc.</i> ....	...	...	C			
— attenuata, <i>Lyc.</i> ....	...	...	C			
Ceromya bajociana, <i>d'Orb.</i> ....	B	...	C			
Goniomya angulifera, <i>Sow.</i> ....	B	...				
Gresslya abducta, <i>Phil.</i> ....	B	...				
Myacites Goldfussi, <i>Oppel.</i> ....	B	...		...	...	Casts.

TABLE B (continued).

Quenstedtia oblita, <i>Phil.</i> .....	...	...	...	D		
Pholadomya Murchisonæ, <i>Sow.</i> ..	...	...	C			
— fidicula, <i>Sow.</i> .....	...	B				
—, large sp. ....	A					
Tancredia axiniformis, <i>Phil.</i> .....	...	...	C			
— donaciformis, <i>Lyc.</i> .....	...	...	C			
Sowerbya elongata, <i>Lyc.</i> .....	...	...	C			
—, sp. ....	...	...	C			
Arconya .....	...	B				
Cypriocardia .....	...	B?	...	...	...	acutangula or bathonica.
— cf. nuculiformis, <i>Röm.</i> .....	...	B?	...	...	...	? C. nuciformis.
Lithodomus Porteri, <i>Lyc.</i> .....	...	...	C			
Avicula clathrata, <i>Lyc.</i> .....	...	...	C			
— Münsteri, <i>Goldf.</i> .....	A	...	C			
— inæquivalvis, <i>Sow.</i> .....	...	...	C			
— braamburiensis, <i>Sow.</i> .....	...	...	...	...	...	*
Lima pectiniformis, <i>Sow.</i> .....	...	...	C			
— cardiiformis, <i>M. &amp; L.</i> .....	...	...	C	...	E	
— ovalis, <i>Sow.</i> .....	...	...	...			
— bellula, <i>M. &amp; L.</i> .....	...	...	C			
— duplicata, <i>Sow.</i> .....	...	...	C			
— punctata, <i>Sow.</i> .....	A	...	...			
Ostrea flabelloides, <i>Lam.</i> .....	A	...	C			
— rugosa, <i>Goldf.</i> .....	...	...	...			
— costata, <i>Sow.</i> .....	...	...	C			
— crista-galli, <i>Quenst.</i> .....	...	B				
— cf. obscura, <i>Sow.</i> .....	...	...	C			
— cf. pyxiformis, <i>Wright</i> .....	A	...	...	...	E	
Pecten articulatus, <i>Schl.</i> .....	...	...	C			
— lens, <i>Sow.</i> .....	A	...	C			
— demissus, <i>Phil.</i> .....	A	...	C			
— clathratus, <i>Röm.</i> .....	...	...	C?			
— personatus, <i>Münst.</i> .....	...	...	C?			
Hinnites velatus, <i>Goldf.</i> .....	...	...	C			
Gervillia acuta, <i>Sow.</i> .....	...	B	C			
— tortuosa, <i>Phil.</i> .....	...	...	C			
Mytilus Sowerbyanus, <i>d'Orb.</i> ..	...	B				
Pinna .....	...	B	C	...	...	Very large species.
Terebratula submaxillata, <i>Mor.</i> ..	A	B				
— maxillata, <i>Sow.</i> .....	...	B				
— perovalis, <i>Sow.</i> .....	...	B				
— plicata, <i>Buckm.</i> .....	...	B				
— cf. trilineata, <i>Y. &amp; B.</i> .....	A	B				
Waldheimia carinata, var. <i>Mandelslohi</i> , <i>Oppel</i> .....	...	B	C			
— anglica, <i>Oppel</i> .....	...	...	C?			
Rhynchonella quadriplicata, <i>Ziet.</i> ..	A					
— subtetraëdra, <i>Dav.</i> .....	A	B	C			
— concinna?, <i>Sow.</i> .....	A	B				
— angulata, <i>Sow.</i> .....	...	B				
— spinosa, <i>Schlot.</i> .....	...	...	C			
— cynocephala, <i>Rich.</i> .....	A					
Diastopora .....	A	...	C			
Serpula socialis, <i>Goldf.</i> .....	...	...	C			
— sulcata, <i>Sow.</i> .....	...	...	C			
— convoluta, <i>Goldf.</i> .....	A	B				
— plicatilis, <i>Goldf.</i> .....	A	...	C			
Pentacrinus .....	...	...	C			
Isastræa serialis, <i>E. &amp; H.</i> .....	...	...	C			
Clausastræa Conybeari, <i>E. &amp; H.</i> ...	...	...	C			

TABLE B (continued).

Thamnastræa Defranciana, <i>Mich.</i>	...	...	C			
—, sp. ....	...	...	C			
Isastræa limitata, <i>Lamx.</i>	...	...	C			
— Richardsoni, <i>E. &amp; H.</i>	...	...	C			
—, sp. ....	...	...				[Wrighti.
Montlivaltia, sp. ....	...	...	C	...	...	sp. approaching M.
— lens, <i>E. &amp; H.</i>	A	B				
Spines of Echinoderms, 2 or 3 sp. ....	...	...	C			
Echinobrissus clunicularis, <i>Ltd.</i>	...	...	...	...	...	*
Astropecten, sp. ....	...	...	...	...	...	*
Pentacrinus, sp. ....	...	...	...	...	...	*
Annulated Algæ. ....	...	...	...	D	E	

Specimens marked \* are from Mr. Windoes' collection.

TABLE C.—Fossils from the Inferior Oolite of Otley Hill.

Ammonites Murchisonæ, <i>Sow.</i>	Pecten articulatus, <i>Schlot.</i>
—, var. corrugatus, <i>Sow.</i>	— demissus, <i>Phil.</i>
— læviusculus, <i>Sow.</i>	— lens, <i>Sow.</i>
— variabilis, <i>d' Orb.</i>	Ostrea flabelloides, <i>Lam.</i>
* Belemnites Aalensis, <i>Ziet.</i>	— Sowerbyi, <i>M. &amp; L.</i>
* — ellipticus, <i>Mill.</i>	Rhynchonella subangulata, <i>Dav.</i>
Nautilus, sp. nov., large.	—, sp.
Pleurotomaria ornata, <i>Ziet.</i>	— cynocephala, <i>Rich.</i>
Natica.	* Terebratula globata, <i>Sow.</i>
* Nerinæa.	— submaxillata, <i>Mor.</i>
Pholadomya fidicula, <i>Sow.</i>	— simplex, <i>Buckm. (Mr. T. J.</i>
* — ovulum, <i>Ag.</i>	Slatter).
— Zieteni, <i>Ag.</i>	— ovoides, <i>Sow.</i>
— Heraulti, <i>Ag.</i>	* Berenicea, sp., on Terebratula.
—, sp. nov., large.	Heteropora conifera, <i>Blainv.</i>
Gresslya latirostris, <i>Ag.</i>	Isastræa Richardsoni, <i>E. &amp; H.</i>
— peregrina, <i>Phil.</i>	— serialis, <i>E. &amp; H.</i>
Ceromya bajociana, <i>d' Orb.</i>	* Montlivaltia trochoides, <i>E. &amp; H.</i>
Cardium striatulum, <i>Phill.</i>	—, cf. lens, <i>E. &amp; H.</i>
Cypriocardia.	Thamnastræa Terquemi, <i>E. &amp; H.</i>
Isocardia cordata, <i>Buckm.</i>	* Thecosmilia gregaria, <i>M. Coy.</i>
* Cucullæa oblonga, <i>Sow.</i>	Clausastræa Conybeari, <i>E. &amp; H.</i>
* Lucina Wrightii, <i>Oppel.</i>	Thamnastræa Defranciana, <i>Mich.</i>
Trigonia costata, <i>Sow.</i>	Serpula.
* — signata, <i>Ag.</i>	Wood.
— pullus, <i>Sow.</i>	Strophodus.
— producta, <i>Lyc.</i>	Astarte minima, <i>Phill.</i>
— Brodiei, <i>Lyc.</i>	Mytilus Sowerbyanus, <i>d' Orb.</i>
— striata, <i>Sow.</i>	Trochotoma, sp.
Astarte, cf. depressa, <i>Goldf.</i>	Trigonia angulata, <i>Sow.</i>
Modiola Lonsdalei, <i>M. &amp; L.</i>	—, sp.
— Leckenbyi, <i>M. &amp; L.</i>	Gresslya abducta, <i>Phill.</i>
Pinna cuneata, <i>Phil.</i>	Astarte, sp.
* —, sp.	Myacites Goldfussi, <i>Mor.</i>
Lima pectiniformis, <i>Sow.</i>	Avicula, sp.
— punctata, <i>Sow.</i>	Serpula convoluta, <i>Goldf.</i>
— cardiiformis, <i>M. &amp; L.</i>	Chemnitzia lineata, <i>Sow.</i> ; cast.
* Gervillia Hartmanni, <i>Goldf.</i>	Tancredia, cf. donaciformis, <i>Lyc.</i>
* — lata, <i>Phil.</i>	Turbo hamptonensis, <i>M. &amp; L.</i>
Hinnites abjectus, <i>Phil.</i> , sp.	Monodonta.

Those marked \* are from Prof. Judd's lists.



*Notes and Corrections (14th April, 1883).*

Some little confusion has been caused by the variable conditions affecting the lower beds A and B of the Hook-Norton series. Whilst some new exposures show them to rest unconformably upon the Upper Lias, attaining at the south end of the cutting a thickness of 5 feet 6 inches, and passing in places into a compact blue sandy limestone, at the north end, and in the adjacent Duckpool-Farm cutting, they are absent altogether. Both at Hook Norton and at Otley Hill *Rhynchonella cynocephala* is found at the top of A, together with *Trigonia striata*, *T. Brodiei*, *Terebratula trilineata*, *Pholadomya fidicula*, *Montlivaltia* cf. *lens*, &c. It is probably the superior bed B which has yielded *Ammonites Murchisonæ*, its variety *corrugata*, and another form like *Amm. variabilis*. It would seem, therefore, as if we had in the lower part of the series an equivalent of the "*cynocephala*" stage of Dr. Lycett, thus confirming my surmise as to the existence of lower Inferior-Oolite beds over the region, and perhaps, in part, representing also Professor Judd's zone of *Ammonites Murchisonæ*.

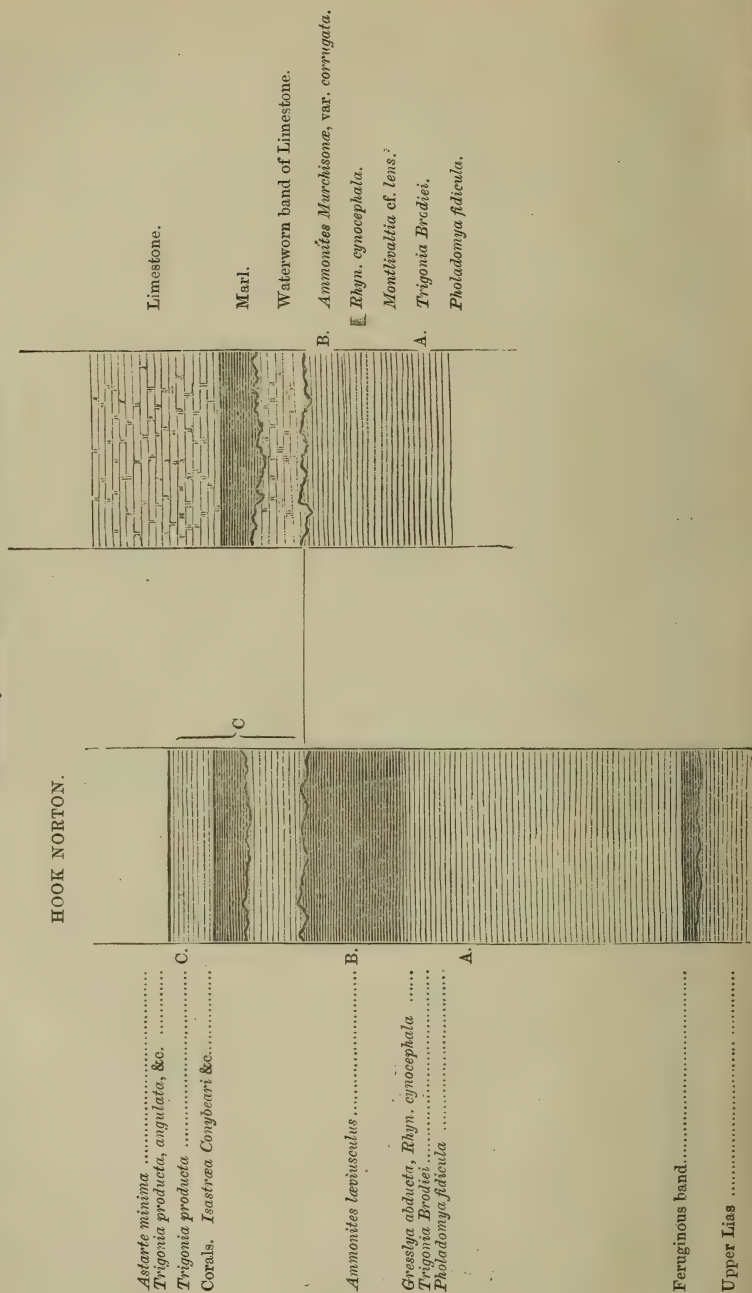
Reposing upon the series mentioned, and just now admirably shown at Otley Hill (*vide* Section, fig. 4, p. 244), is a band of hard, compact crystalline limestone, curiously waterworn both above and below, and measuring but 1 foot 4 inches in thickness. The great erosion it has suffered prior to the deposition of the overlying marls is at once apparent; and it seems to be the dividing line between the lower and upper Inferior-Oolite divisions. The coral-bed at Hook Norton, which I had previously, in error, placed at the top of A, is its equivalent, and is not only filled with concretionary or derived fragments, but is bored and worn at the top. Large masses of *Isastræa serialis* occur in it, accompanied by *Clausastræa Conybeari*, *Terebratula perovalis*, &c., with *Trigonia producta* and *T. angulata* on its upper surface.

## DISCUSSION.

Mr. HUDLESTON bore testimony to the value of the work done by collectors in the neighbourhood of Banbury, both in the Lias and Inferior Oolite. The latter was especially difficult to interpret in North Oxfordshire, which was the border land between the South-western or Gloucestershire types and the North-eastern or Northamptonshire types. He remarked on the confusion which had been produced by the use of the term "Northampton Sand" as applied to beds in this district, since the real Northampton Sand represents the zones of *Amm. opalinus* and *Amm. Murchisonæ*, whilst at Chipping Norton its Oxfordshire namesake overlies the Clypeus-grit, which is in the zone of *Amm. Parkinsoni*. Apart from the question of names, the relations of the Clypeus-grit to the general mixture of sandy limestones was a puzzle to which Mr. Walford's careful observations afforded a clue of great importance.

Prof. JUDD stated that the intricacy in the geology of the district was the result of the rapid thinning-out in passing north-eastward

Fig. 4.—Sections at Hook Norton and Otley Hill, to illustrate Denudation of Lower Beds of the Inferior Oolite of North Oxfordshire.



of different members of the Lower Oolites, and of the different conditions which prevailed in closely adjoining areas. The great sandy series, which had unfortunately been correlated as a whole with the Northampton Sand of the Midlands, appeared to include representatives of both the Great and the Inferior Oolites.

Mr. ETHERIDGE thought it very difficult to correlate these beds of the Chipping-Norton area with those of the Cotteswold Hills. He remarked upon the remarkable attenuation of the Inferior Oolite when traced into the neighbourhood of Bridport. He considered the working-out of the minute geology of local areas would furnish a key to many difficult problems.

Mr. BAUERMAN stated that he had himself drawn the lines in the district represented in the author's map, the work in the remainder of the sheet having been carried on by Mr. Polwhele. He had then assigned the beds to the Inferior Oolite.

Mr. WALFORD stated that his map and the whole of his work had been based on the publications of the Geological Survey. Some artificial openings he had recently made confirmed his views on the succession of beds in the area. Even if some of the beds were equivalent to the Fuller's Earth, these are, as Professor Tate showed, referable to the Inferior rather than to the Great Oolite.

17. *On the DINOSAURS from the MAASTRICHT BEDS.* By H. G. SEELEY, Esq., F.R.S., F.G.S., &c., Professor of Geography in King's College, London. (Read March 7, 1883.)

IN 1871 the Geological Department of the British Museum acquired the celebrated collection formed by Professor van Breda at Haarlem. It was especially rich in the remains of fossil reptiles from Maastricht; and among the bones of *Mosasaurus* were arranged five other specimens, which Mr. William Davies, F.G.S., soon recognized as Dinosaurian. So far as is at present known, these are the most recent evidences of the Dinosaurian order in geological time; and in view of this fact, I am happy in having the permission of Dr. Henry Woodward, F.R.S., the Keeper of the Department, to offer the Geological Society some account of the structure of the last known survivors of the group. I avail myself the more readily of this permission, since I do not remember to have seen in any of the continental museums other specimens exhibited which would add materially to the British-Museum evidence or modify my conclusions.

These five bones belong to two types. One femur is Megalosaurian; and although it is quite possible that other parts of the skeleton may enable their discoverer to refer the animal to a new genus, I have not felt justified in differentiating the genus from *Megalosaurus* on the evidence of one bone, imperfect distally, and with the proximal end worn. The other specimens are Iguanodont. I have referred them to an Iguanodont genus *Orthomerus*; and I have no doubt that the remainder of the skeleton will eventually show them to belong to a new generic type. For more certain reference, I give the British-Museum numbers on the specimens.

#### MEGALOSAURUS BREDAL, Seeley.

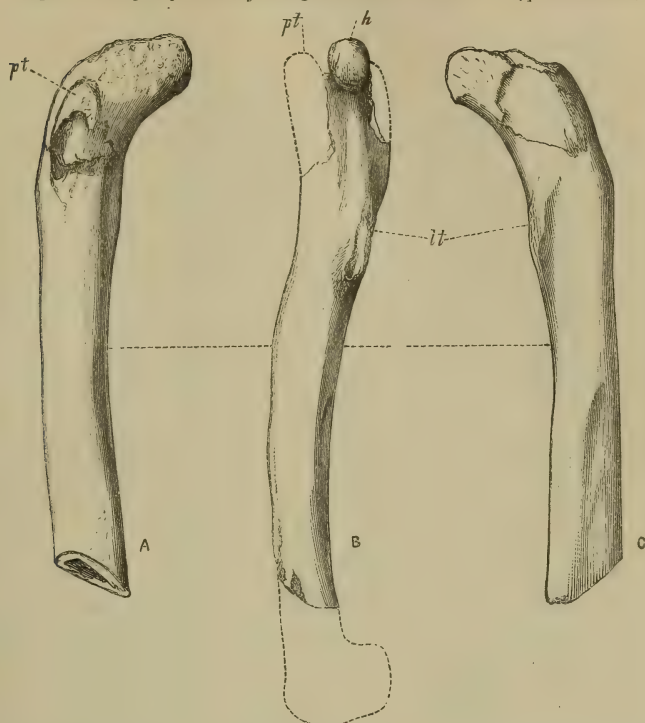
No. 42997. This right femur is of Megalosaurian type.

The bone is very imperfect; the distal end has been sawn away (fig. 1, A), so that the bone shows no indication of the distal articulation, though some changes in the form of the shaft suggest that no large portion is lost (fig. 1, B). The proximal end is a good deal worn and broken away (fig. 1, B); but enough remains to demonstrate its more remarkable characters.

The femur, as a whole, is remarkable for its slender form, its superior bow-shape curvature, the lateral compression of the proximal articulation (fig. 1, B, *h*), and the extent to which it is directed inward, for the proximal trochanter, which is separated from the proximal end of the bone in front (fig. 1, A, *p t*), and for the proximal position and small size of the lateral trochanter (fig. 1, B and C, *l t*).

The fragment, as preserved, is nearly 29 cm. ( $11\frac{2}{5}$  in.) long. The shaft of the bone is unusually compressed from side to side, so as to make the vertical thickness (fig. 1, B) as much as or more than the width (fig. 1, A); and while the surfaces of the bone generally are rounded, the superior or anterior aspect is marked by a blunt ridge



Fig. 1.—*Right femur of Megalosaurus Bredai.* ( $\frac{1}{4}$  nat. size.)

A. Anterior aspect.

B. Inner aspect.

C. Posterior aspect.

*h*, articular head; *pt*, proximal trochanter restored; *lt*, lateral trochanter.

which becomes more angular as it ascends towards the proximal trochanter; but the ridge does not diverge outward much from the median line. At 7 cm. ( $2\frac{3}{4}$  in.) from the proximal end the bone is 41 mm. ( $1\frac{2}{3}$  in.) thick and 39 mm. ( $1\frac{4}{7}$  in.) wide. At 13 cm. ( $5\frac{1}{8}$  in.) from the proximal end the thickness is 35 mm. ( $1\frac{2}{5}$  in.), and the width 32 mm. ( $1\frac{1}{3}$  in.). At the distal end the bone becomes more flattened, and widens a little; the thickness is 28 mm. ( $1\frac{1}{8}$  in.), and the width 38 mm. ( $1\frac{1}{2}$  in.); the increase in distal width is chiefly a widening on the inner side, which becomes vertical. The external margin, though slightly concave, is nearly straight; viewed from the outside it has an aspect proximally of broad inflation, which becomes much reduced towards the distal end, chiefly owing to the increasing convexity of the inferior or posterior surface. But there is a slight elevation at about 8 cm. ( $3\frac{1}{7}$  in.) from the proximal end; and the external surface curves inward from this point as it extends proximally, forming a sharp angle with the distal part of the external margin. The posterior surface in its distal half has a median longitudinal rounded ridge which fades away distally, and inclines a little towards the inner side of the bone.

The lateral trochanter (*lt*, figs. B and C) is rather less than 5 cm. (2 in.) long, tapers proximally and distally, is compressed from above and below, and shows on the anterior side a small muscular scar, which deepens towards the distal border. The trochanter extends within about  $7\frac{1}{2}$  cm. (3 in.) of the proximal end; it is directed a little inward and backward. At the upper limit of the trochanter the shaft is approximately triangular, being flattened below, while the inner and outer sides converge to the median anterior ridge.

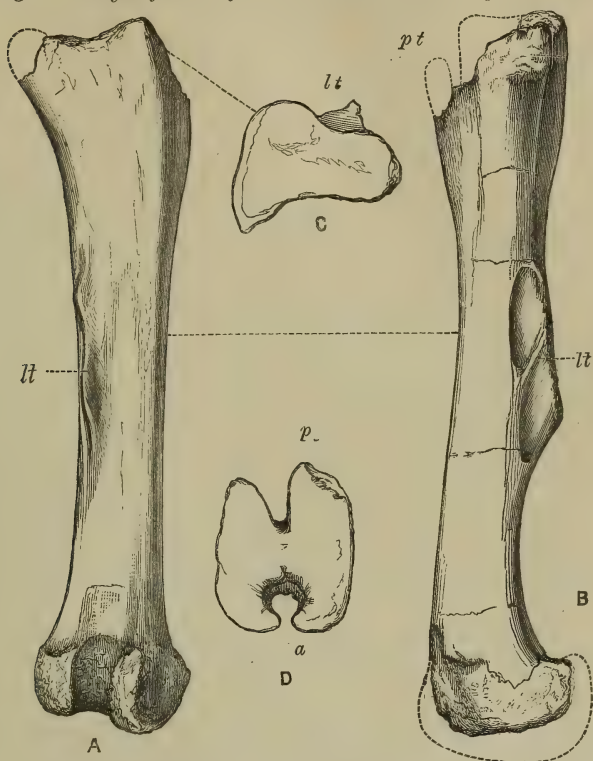
The head of the bone (*h*, fig. B) has the aspect of being bent inward, the external outline being strikingly convex, and the inner border concave, so that the transverse width of the head, as preserved, is not more than  $6\frac{1}{2}$  cm. ( $2\frac{2}{7}$  in.). Externally and superiorly there was a trochanter, which formed an angular ridge; it was divided from the head of the bone by a vertical groove, but must have been short, since the bone could not have extended more than from 1 to 2 cm. proximally beyond the base of the groove which proves its existence. Internal to this trochanteric ridge the bone is compressed and concave. As preserved, the articular head of the bone is 2 cm. ( $\frac{4}{5}$  in.) thick, and less than 3 cm. ( $1\frac{1}{5}$  in.) deep; but it is abraded, and there is no trace left of articular surface, or of the proximal cartilaginous tissue of the bone, which from within outward did not measure more than 6 cm. ( $2\frac{4}{11}$  in.), and now measures rather less; the posterior surface behind the articular head is somewhat inflated, so as to make the transverse section semicircular. Seen from the inner side the head of the bone is inclined towards the inner trochanter, so that it has a slightly oblique appearance as to its vertical direction (fig. B); but it is almost at right angles to the external surface of the shaft.

The differences of this bone from the femur of *Megalosaurus Bucklandi* extend to almost every detail: first, the distal end of the bone is compressed from front to back, while in *Bucklandi* it thickens; the lateral internal trochanter is much more proximal in position; the external trochanter is much much closer to the head of the bone in this specimen, and more proximal in position; the curvature of the shaft is relatively greater, and its antero-posterior thickness is greater.

#### ORTHOMERUS DOLLOI, Seeley.

No. 42955. A large femur (fig. 2), which is slightly imperfect at its articular ends, measures  $49\frac{1}{2}$  cm. ( $19\frac{1}{2}$  in.) in length. The shaft is remarkably straight and strong. The bone is subtriangular at the proximal end, is subquadrate but wider than thick in the lower part of the shaft, and has the lateral trochanter in the middle of the shaft, with the proximal and distal ends modified on the Iguanodont plan.

The distal end of the femur is fractured in front (fig. 2, B), where the condylar portion was probably a little expanded anteriorly, as in a second and smaller specimen (fig. 2, D). Across the condyles of the type the measurement is fully 10 cm. (4 in.). The posterior inner condyle is considerably the larger; and the two are divided by a deep concave channel (fig. 2, A). The external or anterior distal condyles were similarly divided by a concavity, so that the thickness of

Fig. 2.—*Right femur of Orthomerus Dolloi.* ( $\frac{1}{5}$  nat. size.)

- A. Posterior aspect: *lt*, lateral trochanter.  
 B. Inner lateral aspect: *pt*, proximal trochanter.  
 C. Outline of proximal end, reversed.  
 D. Outline of distal end of another specimen (B. M. No. 42957).  
*a*, anterior, *p*, posterior condyles.

bonedividing the anterior and posterior surfaces on the distal face of the articulation is about 3 cm. ( $1\frac{1}{5}$  in.). External to the outer of the posterior condyles is a slight ridge, which is rounded and situate behind the middle of the outer side of the bone, so as to make the shorter posterior area markedly concave and to form a slight concavity anteriorly. This modification, which is limited to the condylar region, has the effect of giving the outer posterior condyle a compressed aspect, and makes the bone compressed posteriorly. Distally there is a moderate concavity between the condyles from within outward; but the articular surface is imperfectly preserved, though the outer condyle appears to have had the greater distal extension. The depth of the inner condyle is about 6 cm. ( $2\frac{4}{11}$  in.). The width across the condylar region, as preserved, is 10 cm. (4 in.). The antero-posterior measurement cannot be given. Above the condyles the distal end of

the shaft is concave from side to side posteriorly; the concavity, diminishing in amount, extends proximally towards the region of the lateral trochanter. The width of the shaft just above the condyles is under 9 cm. ( $3\frac{4}{7}$  in.); and the median thickness of the shaft is under 5 cm. (2 in.). The two sides of the shaft converge a little towards the base of the lateral trochanter; and the sides converge upward towards the anterior surface so as to give the front of the bone a convex or subcylindrical aspect in its middle third. Distally, towards the condyles the front of the bone is gently concave; but the concavity narrows and deepens rapidly to descend between the anterior expansions of the condyles, which are broken away.

The lateral trochanter and muscular ridge (fig. 2, A, B, *lt*) extends to within 19 cm. ( $7\frac{3}{5}$  in.) of the distal end, is nearly 14 cm. ( $5\frac{1}{2}$  in.) long, and extends to within about 15 cm. (6 in.) of the proximal end. It is a compressed curved process which is directed mainly backward and a little inward, and is much more developed in its distal half than in the proximal part. It owes its existence to two powerful muscular attachments, which are on the inner side of the bone; they partly overlap each other, so that the proximal scar descends partly in front of the distal impression. The proximal scar is about 8 cm. ( $3\frac{1}{4}$  in.) long, and 3 cm. ( $1\frac{1}{5}$  in.) wide; less than half of its width is attached to the trochanteric process. The distal scar is quite as long and as wide, but is pointed proximally, rounded distally, is much deeper, and is chiefly attached to the trochanter (fig. 2, B, *lt*). The posterior edge of the trochanter, which is inclined obliquely backward (fig. 2, A), is nearly parallel to the anterior borders of the muscular scars. The width of the shaft just below the trochanter is 6 cm. ( $2\frac{4}{11}$  in.); its thickness in the same position is 5 cm. (2 in.).

Proximally, above the trochanter the form of the shaft alters, becoming compressed and well rounded on the inner surface, and greatly widened on the external border, so that the transverse section is subtriangular (fig. 2, c); the anterior surface is broadly concave, with the concavity increasing as the proximal trochanteric ridge is developed externally; the posterior surface is flattened, with a moderate median longitudinal concavity; and the external surface is flattened along its whole extent, but is a little convex from above downward, and has a broad shallow concavity behind the lateral trochanter.

No. 42957. A second specimen is smaller, and worth describing because it shows the form of the distal end (fig. 2, d).

This fragment consists of the shaft and distal end of a Dinosaurian femur of moderate size. The fragment measures 30 cm. ( $11\frac{4}{5}$  in.) in length, and extends for about 3 cm. ( $1\frac{1}{5}$  in.) beyond the internal lateral trochanter. The shaft is more quadrate in section than in the larger specimen, is more concave on the inner margin, has a slight convexity in length on the external border, and exhibits various minor details of structure.

The width of the shaft just below the lateral trochanter at 13 cm. ( $5\frac{1}{8}$  in.) from the distal end is  $3\frac{1}{2}$  cm. ( $1\frac{2}{5}$  in.); the thickness in the same position is just over 4 cm. ( $1\frac{4}{7}$  in.).



The extreme length of the lateral trochanter is  $10\frac{1}{2}$  cm. ( $4\frac{1}{8}$  in.); it is directed backward only. It is narrow, being compressed from side to side, and is most elevated in the middle, while in the larger specimen the greatest elevation is below the middle. One muscular attachment extends along the whole of its inner border, tapering above and below; while proximally there is a vertically ovate impression, nearly 5 cm. (2 in.) long, which runs side by side with the proximal part of this impression.

The sides of the shaft are remarkably parallel, flattened behind and on the external surface, rounded in front and on the internal surface, though the convexity decreases distally.

On the external surface is a longitudinal median muscular scar about 5 cm. (2 in.) long; it is rugose in the middle; and extends to within about  $11\frac{1}{2}$  cm. ( $4\frac{1}{2}$  in.) of the distal end.

The outline of the distal end is like the letter H, owing to the way in which the anterior and posterior channels between the condyles cut into the bone (fig. 2, d). The inner condyle, as usual, is much the larger posteriorly (fig. 2, d, p), measuring 9 cm. ( $3\frac{4}{8}$  in.) from front to back, while the outer condyle is only 8 cm. ( $3\frac{1}{4}$  in.) from front to back, and it is much more compressed from side to side, especially proximally.

The transverse measurement over the condyles is  $7\frac{1}{2}$  cm. (3 in.). Anteriorly the condyles are deeply channelled by a nearly circular canal (fig. 2, d, a) which descends obliquely downwards and backward and expands on the distal surface, so as to be broader than the posterior channel.

The extreme width of the proximal expansion of the bone on the external surface, as preserved at the base of the trochanter, is under 9 cm. ( $3\frac{3}{4}$  in.). The trochanteric process is subtriangular; it is broken away, but its base is defined by a narrow groove extending backward.

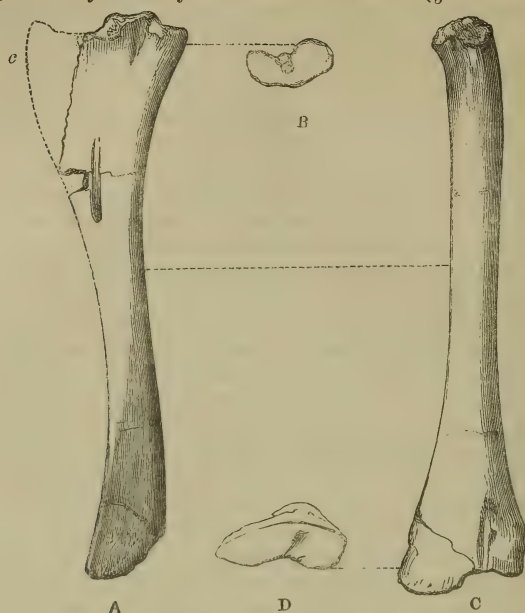
The proximal articular end is entirely broken away, though slight traces of its deep median concavity remain on the posterior border.

On the external lateral aspect is a large rough surface, which is an ill-defined very shallow muscular attachment. It is about 9 cm. ( $3\frac{3}{4}$  in.) long, nearly as broad as the lateral surface, is more distal in position than the lateral trochanter on the opposite inner side of the bone, and extends to within about 17 cm. ( $6\frac{7}{10}$  in.) of the distal articular surface.

In the main characters this form of femur closely resembles *Iguanodon*; in nearly all points in which it differs, it approximates to *Hadrosaurus*.

No. 42954. Left Tibia (fig. 3). This is a long slender bone, which exhibits the distinctive characteristics of the tibia, although the articular surfaces are gone from both ends, and the cnemial crest is entirely sawn away (fig. 3, A), so as to give the specimen somewhat the aspect of a slender humerus. The bone, as preserved, is 27 cm. ( $10\frac{3}{5}$  in.) long. The proximal end is at right angles to the distal end (fig. 3 c). On the whole the specimen shows the nearest resemblance to *Iguanodon*, but is much more slender, and shows some difference in form.

The distal end (fig. 3, d), as preserved, is under 9 cm. ( $3\frac{3}{4}$  in.) wide; Q. J. G. S. No. 154.

Fig. 3.—*Left tibia of Orthomerus Dolloi.* ( $\frac{1}{5}$  nat. size.)

- A. Outer lateral aspect: *c*, cnemial crest.  
 B. Outline of proximal end, reversed.  
 C. Posterior aspect. D. Outline of distal end.

the shaft widens distally in a wedge shape (fig. 3, c), is flattened in front much more than in *Iguanodon*, with a moderate median concavity for the ascending process of the astragalus, which was more than 2 cm. ( $\frac{4}{5}$  in.) wide. On the outer border the bone appears to have formed a slight ridge in the distal 5 cm. (2 in.), though the ridge is abraded and lost.

The external fibular area, which in Dinosaurs is usually well defined by a sharp angle, is here ill defined, about 2 cm. ( $\frac{4}{5}$  in.) wide, and almost in the same plane with the remainder of the distal end of the bone. The fibular margin is sharp, sharper than in *Iguanodon*, though, from the abrasion of the posterior surface, it appears to be sharper than it really is. The fibular side appears to extend outward more rapidly than the inner side, as usual; but the inner side does not widen rapidly, as in *Iguanodon*. At 8 cm. ( $3\frac{1}{4}$  in.) from the distal end the width of the bone is 6 cm. ( $2\frac{4}{11}$  in.); at 10 cm. (4 in.) the width is 5 cm. (2 in.), at 12 cm. ( $4\frac{7}{10}$  in.) it is 4 cm. ( $1\frac{3}{5}$  in.). At 15 cm. (6 in.) from the distal end the bone is 3 cm. ( $1\frac{1}{5}$  in.) from back to front and 3 cm. wide.

The posterior aspect of the bone is marked by a rounded median ridge (fig. 3, c), which becomes narrower and less elevated distally; two thirds of the bone lie on its fibular side, which is flattened and

compressed, and one third on the inner side, which is necessarily more oblique and rounded.

Since the head of the bone is nearly at right angles to the distal end, it necessarily happens that there is no appreciable increase in width as the bone extends proximally. But on the external surface the bone curves a little outward and forms a compressed area, convex from front to back, which terminates proximally in two small convex condylar surfaces (fig. 3, B). The internal aspect of the proximal surface is decayed, so that no account of it can be given.

The cnemial crest (fig. 3, A, c) was evidently developed on the Iguanodont plan; but its proximal portion has been sawn away.

The anterior outline of the bone, as preserved, is concave; the posterior outline is sigmoid (fig. 3, A). The posterior surface shows at 12 cm. ( $4\frac{7}{10}$  in.) from the proximal end a large vascular perforation in the bone, which, as it rises proximally, becomes a groove (fig. 3, A).

As compared with *Iguanodon* this specimen differs chiefly in being more slender and in some details of conformation of the distal end. But although the differences are suggestive of generic distinction, the condition of preservation does not admit of the enunciation of generic characters. On the other hand the form closely approximates to *Hadrosaurus*, and is certainly intermediate between *Iguanodon* and that type\*; and this combined with the characters of the femur indicate a divergence from *Iguanodon* in the same direction as in that bone, which justifies the association of the tibia, femur, and metatarsal bone. The metatarsal bone is too imperfect for description, but it differs in form from any similar bone that has been figured.

#### DISCUSSION.

The PRESIDENT remarked upon the interest attaching to these latest known of the Dinosaurs.

Dr. WOODWARD referred to an Iguanodont vertebra in the British Museum which was dredged from the Dogger Bank. Possibly this was derived from the Maastricht beds, and Prof. Seeley might be able to associate it with the bones described in the paper.

The AUTHOR stated that many Iguanodont remains were found in the Crag and the Drift; but it would be unsafe to infer any possible relations to one another.

\* It may be also compared with the tibia referred to *Megalosaurus* by Prof. Owen (Rept. Weald, part iii., 1856), but will be seen to be of distinct type.

18. ADDITIONAL NOTE on BOULDERS of HORNBLLENDE PICRITE near the WESTERN COAST of ANGLESEY. By T. G. BONNEY, M.A., F.R.S., Sec. G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read April 25, 1883.)

IN a short communication printed in this Journal (vol. xxxvii. p. 137) I described a large boulder of hornblende picrite which I found near Pen-y-Carnisiog in the autumn of 1880. Last summer I had an opportunity of spending an afternoon upon the western coast of Anglesey, and made use of it to examine the interesting section to the south of Porth Nobla. I did not, however, neglect to look out for boulders, as I thought it not impossible that I might meet with some more picrite. In this I succeeded beyond my expectations, and now lay the results before the Society, together with some remarks on the microscopic structure of the specimens collected.

After quitting the railway at Ty Croes Station, I walked a short distance along the road to the south-west, and then turned up a field-way leading past a small farm called Bryn Gwyn. A short quarter of a mile from it a boulder (No. I.), perhaps roughly trimmed, has been utilized as the capstone of a gate-post. It measures  $2\frac{3}{4} \times 2 \times 1\frac{1}{4}$  feet\*. A small fragment projected, which I was able to detach for examination without injury to the stone.

The next (No. II.) was a well-rounded boulder lying on the sandy shore at Porth Nobla. This had a rather greener matrix than those which I had previously seen: and the porphyritic hornblende or augite crystals were not quite so large. It measured about 2 feet each way, and rose about 1 foot above the sand. Near the shore, in the little cove Pen-y-Cnwe, is a boulder measuring about  $4\frac{1}{2} \times 3 \times 2$  feet (No. III.), and within a short distance a smaller one about 2 feet in longest diameter. At the cromlech Barclodiad-y-gawras, further south, two of the supporting stones on the western side are, I have no doubt, picrite of the ordinary type; but of course I did not touch these with my hammer. Three others are dark augitic (or hornblendic) gabbro-like rock, common in boulders in this part of Anglesey.

On my return from Langwyfen to Ty Croes, by Frondwl, I noticed a small picrite boulder built into a wall by the road-side; and then (a little over a mile from the station, and perhaps 300 yards from a chapel) I found no less than seven fragments of picrite, five of them being built into a rough wall, and one lying on either side of it (No. IV.) They ranged from about 2 to 4 feet in longest diameter; but the time at my disposal did not allow me to go into details. I should suppose they were fragments of one boulder; if so, it must have been even larger than that which I saw at Pen-y-Carnisiog.

\* Measurements throughout are only approximate.



I have examined microscopically specimens from four of the above localities. Numbers III. and IV. are, macroscopically, almost undistinguishable from the Pen-y-Carnisiog specimens; nor is there any material difference under the microscope. The larger hornblende crystals in III. are commonly a light brown, but occasionally a pale green. The smaller crystals are more commonly green. Small portions of some of the larger crystals, sometimes external, sometimes internal, are almost colourless, and have a rather more milky aspect than the rest of the crystal. With crossed nicols they exhibit a different tint, but extinguish either at or as nearly as possible at the same angle. Still, even then, on introducing a quartz plate, a marked difference of tint is perceptible. Whether this change denotes an hydration of the hornblende or a paragenesis of two slightly different varieties, I cannot say. Cracks in the crystals are often filled, and the edges bordered, with a minutely granular mineral, giving light specks of colour with crossing nicols. In parts of the slide are many small grains and clusters of a mineral now consisting of aggregates of this secondary mineral and of earthy-looking dust. These may possibly have been a rather aluminous augite; this mineral, however, as in the case of the Pen-y-Carnisiog rock, cannot be certainly identified in the slide. There are numerous grains of a dark brown mineral, in some cases feebly translucent, in others including granules of a clear light-brown mineral; a few appear to be sections of octahedra. They present a resemblance to chromite; but, as no chromium has been detected on analysis, this mineral can hardly be present; possibly they are spinel. For the various pseudomorphic products occupying the rounded grains in the larger crystals, and the general ground-mass of the slide, I may refer to my former paper. I do not identify mica. It is just possible that the slide may have contained a crystal or two of felspar.

No. IV. differs so little from the last that a separate description is needless; there can, I think, be no doubt that some of the serpentinous aggregates replace olivine. One exhibits an approach to aggregate polarization. There is a little apatite, and a few scales of brown mica.

No. II. presents, macroscopically, some slight varietal differences: the ground-mass is greener; and the imbedded hornblende crystals are not quite so abundant or large as in the other cases, being commonly from 0.2 to 0.3 inch in diameter. But the microscopic structure has a close general resemblance to that above described, though it contains a few grains of a serpentinous mineral which I have not observed in the others. This has a rather irregular outline, is nearly colourless, is of a somewhat silky structure, with rather infrequent cleavage-planes parallel with the fibres of this structure; it extinguishes when they coincide with the vibration-plane of either of the crossed nicols. Numerous minute belonites, slightly browner in colour, occur in the grains, lying often so as to cross one another at angles of about  $120^\circ$ , and to be very nearly bisected by the cleavage-planes. I have already noticed this microlithic structure, sometimes with minute rods of opacite, in one of the minerals of various serpen-

tinous rocks, and think that probably we have here an altered enstatite\*. The slide, however, does not exhibit in any part the peculiar brassy lustre of bastite.

No. I., though in many respects agreeing with the first described, has one or two varietal differences. There is undoubtedly a little plagioclastic felspar, rather decomposed, with a considerable amount of an almost colourless mineral, containing fine earthy granules, acting rather feebly on polarized light, and without a very characteristic cleavage, which I am disposed to regard as akin to augite. Some of the brown hornblende crystals seem to pass through a narrow green border into a closely cleaved colourless mineral like a diallage, with a larger extinction-angle than that of hornblende. Indeed, more than one specimen in the above-described rocks, though strongly dichroic, more resembles diallage in aspect, and has an extinction-angle too large for hornblende. The Schriesheim rock, said to contain diallage, gives a similar discrepancy. I am disposed to explain the apparently contradictory results afforded by these rocks by supposing that the mineral originally predominating in the picrite was a pyroxene, and that we find it now in various stages of conversion into hornblende.

I am indebted to the kindness of my friend Mr. J. A. Phillips, F.R.S., for a duplicate analysis of the rock collected on the road to Ty Croes station (No. IV.), which I subjoin:—

	I.	II.
Water { hygrometric .....	0·60	0·53
{ combined .....	2·84	2·90
Silica .....	42·94	42·79
Alumina .....	10·87	10·98
Carbonic anhydride .....	2·65	2·76
Phosphoric anhydride .....	trace	trace
Ferric oxide .....	3·47	3·40
Ferrous oxide .....	10·14	10·13
Titanic oxide .....	trace	trace
Manganous oxide .....	trace	trace
Lime .....	9·07	9·15
Magnesia .....	16·32	16·22
Potassa .....	0·15	0·10
Soda .....	0·90	0·93
	<hr/>	<hr/>
	99·95	99·89
Specific gravity .....	2·88	2·88

Nickel and chromium were sought for but not found.

For comparison, I append a series of analyses of picrite. The first five are given by Tschermak (Sitzungsb. Akad. der Wissenschaften. Wien, vol. liii. pt. 1, p. 260). The next two are 'palæopicrite'

\* A similar structure, but with the rods more nearly at right angles, is figured as occurring in magma-basalts by Borický, 'Basaltgesteine Böhmens,' pl. i.

	SiO <sub>2</sub> *	Al <sub>2</sub> O <sub>3</sub> *	Fe <sub>2</sub> O <sub>3</sub> *	FeO.	CaO.	MgO.	K <sub>2</sub> O.	Na <sub>2</sub> O.	H <sub>2</sub> O.	CO <sub>2</sub> *	Total.
Söhle, near Neuttschein .....	38.9	10.3	4.9	7.0	6.0	23.6	0.8	1.3	4.5	1.8	99.1
Freiberg and Gumbelberg .....	40.79	10.41	3.52	6.39	8.48	23.34	0.71	1.71	4.04	trace	99.39
Schönan .....	38.72	10.19	6.30	6.14	10.37	18.59	1.57	1.50	3.96	2.93	100.27
Söhle (looking rather decomposed) ..	42.85	10.42	6.27	6.86	11.84	9.01	1.61	1.65	2.70	5.88	99.09
Bystrye .....	33.01	15.83	2.75	7.62	13.61	7.28	1.81	0.59	4.23	11.97	98.70
Schwarzenstein, N.E. of Hof .....	37.12	4.96	8.92	7.62	6.14	26.92	0.49	0.40	5.04	0.09	98.60*
Holler, near Lichtenberg .....	41.48	3.61	6.26	8.46	6.55	25.27	0.09	0.29	4.57	0.17	97.47†
Otenschlag, S. Austria .....	45.93	15.09	1.87	11.45	8.92	14.82	0.22	1.93	0.58	.....	100.81
Schriesheim an der Bergstrasse .....	41.44	6.63	13.87	6.30	7.20	18.42	0.93	0.24	5.60	.....	100.63

\* Including TiO<sub>2</sub>=0.4, MnO=0.4, PO<sub>5</sub>=0.10, and trace of chromium oxide.

† Including TiO<sub>2</sub>=0.18, MnO=0.37, PO<sub>5</sub>=0.17, and trace of chromium oxide.

from Gumbel, 'Geognostische Beschreibung des Fichtelgebirges,' p. 152; then 'palæopicrite' analyzed by Alois Gamroth, 'Jahrbuch k.-k. Reichsanst.' 1877, Min. Mitth. p. 278; the last, the Schriesheim rock, analyzed by Fuchs, 'N. Jahrbuch,' 1864, p. 326.

By a comparison of these analyses with those made by Mr. J. A. Phillips, we see that the latter have slightly more silica, considerably more alumina, and less magnesia than the two rocks described by Prof. Gumbel, the composition of which more nearly corresponds (except that there is less water) with that of a normal serpentine, from which they differ chiefly in a lower percentage of magnesia and a higher one of lime. Even these, however, differ in the ratio of the silica to the magnesia, which in the Schwarzenstein rock is about 13:10, in the Holler 16:10, while in such a rock as the serpentine of the Lizard, Cornwall, it is roughly 11:10. In the first rock from Söhle it is about 15:10. In the Welsh rock it is rather more than 26:10; but then this ratio is exceeded by two of Prof. Tschermak's specimens, while in the Schriesheim rock it is 22·5:10.

This last has also been called a "Schillerfels" and an olivine-diallage rock; but the conspicuous mineral is not bastite, and my specimen contains little, if any, normal diallage.

For comparison I append one or two analyses of serpentines and of olivine rock.

	I.	II.	III.	IV.
SiO <sub>2</sub> .....	38·86	38·58	38·50	43·84
Al <sub>2</sub> O <sub>3</sub> .....	2·95	3·06	1·02	1·14
Fe <sub>2</sub> O <sub>3</sub> .....	1·86	1·95	4·66	.....
FeO .....	5·04	5·10	3·31	8·76
MnO .....	trace	trace	.....	0·12
NiO .....	0·28	0·30	0·59	0·51
Cr <sub>2</sub> O <sub>3</sub> .....	0·08	0·08	.....	0·42
CaO .....	trace	trace	1·97	1·71
MgO .....	34·61	34·32	36·40	44·33
K <sub>2</sub> O .....	0·33	0·30	} 1·37	.....
Na <sub>2</sub> O .....	0·77	0·76		.....
H <sub>2</sub> O .....	15·52	15·52		1·06
FeS .....	.....	.....	0·41	.....
	100·30	99·97	100·58	101·89

I. & II. Duplicate analyses of a Lizard serpentine by Mr. J. A. Phillips (Phil. Mag. Feb. 1871).

III. Analysis of a serpentine from near Cadgwith by Mr. Hudleston (Q. J. G. S. vol. xxxiii. p. 925).

IV. Olivine rock from St. Paul's Island (Renard, 'Challenger Voyage,' Narrative, vol. ii. p. 7).

In short, an examination of the former analyses shows that the chemical composition of the rock picrite is rather variable, and that, while it lies closer to the normal peridotites than to any other, it is, to



some extent, intermediate between them and the olivine-diabases\*, that it is, in fact, (or has been) an augite- (or hornblende-) olivine rock, rather than an olivine-augite (with or without enstatite†), and that felspar is a common accessory mineral. Consideration, however, of these analyses, and of the structure of the Anglesey rock, both macroscopic and microscopic, fully justifies us in retaining it among the picrites or palæopicrites, if the latter term be preferred.

It is evident from the above observations that this rock is likely to be commonly met with in Anglesey; and I have described it with minuteness in the hope that geologists will be on the watch for its occurrence. I have not yet been able to hear of its being found *in situ* in the Welsh area; but at the end of last year my friend Mr. Teall called my attention to a rock which he had collected at Little Knot, on the east side of Bassenthwaite Lake, which bore, macroscopically, a considerable resemblance to my specimens.

This rock is described as a diorite by the late Mr. Clifton Ward, in the Memoirs of the Geological Survey (Lake District), and a figure of its microscopic structure is given. He remarks on the abundance of hornblende, and the "very little felspar," but does not seem to have suspected that olivine had been present, although, from the figure, I have little doubt that such was the case. A slide cut from Mr. Teall's specimen exhibits well-marked crystals of hornblende, both green and brown, with rounded serpentinous interruptions, and the same pale edging as is seen in some of the Welsh specimens; there is much fibrous actinolite in the body of the slide, and various patches with the peculiar belonites crossing one another, as in some bastite. In many of them are minute rounded specks of granulated aspect, dustier at the edges, and giving with crossed nicols a pale whitish colour. There is a little apatite, a decomposed iron oxide, probably ilmenite, and one or two crystals of felspar, so much decomposed as hardly to be recognizable. The specific gravity of this rock is 2.93. A partial analysis (duplicate), kindly made for Mr. Teall by Mr. E. K. Stock, gives  $\text{SiO}_2 = 46.37$  and  $46.42$ ,  $\text{MgO} = 15.73$  and  $15.30\pm$ . These percentages are not in very exact agreement with those in the Welsh specimen ( $\text{SiO}_2 = 42.94$  or  $42.79$ , and  $\text{MgO} = 16.32$  or  $16.22$ ); but the rock is evidently a variable one, and in mineral composition, macroscopically and microscopically, there is a very near resemblance. It

\* These have, as a rule, a higher percentage of  $\text{SiO}_2$  and still more of  $\text{Al}_2\text{O}_3$ . The analyses of troktolite, especially of that from Volpersdorf (see Houghton, Geol. Mag. dec. ii. vol. vi. p. 504), have a closer correspondence with that of this Welsh picrite; but troktolite is at once distinguished by its poverty in a pyroxenic or hornblende mineral. In it also felspar is conspicuous, while in the picrite it is rare.

† In some of these, *i. e.* the peridotites (and the serpentines resulting from their alteration), the percentage of magnesia somewhat exceeds that of silica; this would be the case where olivine was far the most abundant mineral. An increase in the amount of the enstatite would correspond with a rise in the  $\text{SiO}_2$ : an increase in the augite would be indicated by a marked percentage of  $\text{CaO}$ .

‡ I have since received, through Mr. Teall, other specimens from Mr. A. Bloomfield, of Keswick. He states that there are seven or eight outcrops of the rock, one of which is quarried. The rock is evidently very variable in character.

is therefore possible that these Anglesey boulders have not been derived from that island or North Wales, as I had anticipated, but from the Bassenthwaite district. In admitting the possibility of this, I should not feel bound to regard them as proofs of the former extension of Cumberland glaciers to the Welsh area, but should consider them, like the Criffel and other northern boulders in North Wales and the Midlands, to have been transported by floating ice during the last great submergence.

#### DISCUSSION.

Mr. HUDLESTON thanked the author for his definition of the exact nature of picrite, and remarked on the high alumina percentage of the analysis as being inconsistent with the composition of picrite. He thought the original home of these boulders was not the Lake District, but Anglesey, as suggested by the author in his first paper.

Mr. TEALL said that the Inchcolm picrite contains a very variable quantity of felspar. He thought the presence of felspar in greater proportion could therefore scarcely be regarded as sufficient to differentiate the Lake-District rock from that of Anglesey. He cited a case of the occurrence of a boulder of faulted slate, evidently from the Lake District, in North Wales.

Mr. DE RANCE cited examples of this rock from several localities in Flint, Denbigh, and Caernarvonshire, in boulder-clays, and associated with characteristic Lake-District rocks. The faulted-slate rocks of the Lake District were perfectly distinct in colour and other characters from those of North Wales.

The AUTHOR, in reply to Mr. Hudleston, stated that picrite was a very variable rock. He had difficulty in accounting for the high percentage of alumina; for as a rule he had failed to detect felspar. The Little-Knot rock is quite an exceptional one, as stated by Mr. Clifton Ward. He knew of no example of rocks of the kind in Anglesey.

19. *On the SUPPOSED PRE-CAMBRIAN ROCKS of ST. DAVID'S.* By ARCHIBALD GEIKIE, Esq., F.R.S., F.G.S., Director-General of the Geological Survey. (Read March 21 and April 11, 1883.)

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## INTRODUCTION.

SOME explanation is required of the grounds on which another contribution is added to the already voluminous literature connected with the rocks of St. David's. The circumstances under which I have reluctantly found myself compelled to make this contribution are briefly these.

A new edition of the Rock Catalogue of the Museum of Practical Geology, Jermyn Street, being required, it became necessary to ascertain how far the stratigraphical order followed in previous editions required to be modified by the results of more recent research. In particular, the question of the existence of Pre-Cambrian rocks in Wales, which has emerged since the last issue of the Catalogue, appeared to demand full recognition in any republication of the work. I felt it to be due to those authors who have written so largely on this subject that ample acknowledgment of the results of their labours should be given. On the other hand, I was equally desirous that in admitting corrections of the views expressed upon the maps and sections of the Geological Survey I should do so from an actual inspection of the ground, which would enable me to judge how far and in what manner the required alterations should be made.

It was obvious that in maps of districts surveyed forty years ago some important structures might have escaped notice, positive errors might have been committed, and petrographical details could not be expected to have been treated in a more satisfactory manner than in other English geological works of the same date.

The existence of Pre-Cambrian rocks in South Wales had been

proclaimed so loudly and persistently that, in spite of the protests of my predecessor, Sir Andrew C. Ramsay, who will not admit the presence of such rocks in any part of the Principality, I had gradually been led to believe that they really must exist, though probably not to the extent that had been claimed for them. In visiting Wales, therefore, I went with no prejudice in favour of the views expressed by the Geological Survey. On the contrary, I had a conviction that these views must be, in some measure, at least, erroneous, and that this admission ought to be frankly made.

I chose the St. David's district as being that about which most had been written, and which had, in a measure, been taken as a typical area for the "Pre-Cambrian" rocks of Wales. It is desirable at the outset that it should be clearly understood that the conclusions to which I have come refer solely to that district, and that, in the meantime, I offer no opinion regarding other so-called Pre-Cambrian areas in the Principality.

That my examination of the ground might be made in greater detail, I requested my colleague Mr. B. N. Peach, of the Geological Survey of Scotland, to accompany me. His long experience among crystalline rocks of many kinds has given him great practical insight into the structure of these formations in the field. Like myself, he went prepossessed in favour of "Pre-Cambrian" ideas.

We visited all the sections together, and came to complete agreement in our interpretation of them. The following pages give an account of our joint research in the field, and of my own subsequent petrographical investigation of the rocks collected by us\*.

The earliest published account of the rocks of St. David's appears to have been that given by Dr. Kidd, in vol. ii. of the First Series of the Society's 'Transactions.' This author speaks of the rocks as being in some instances "stratified," in others "unstratified;" the hills, or rocky summits, consisting of materials that "bear no marks of regular stratification," but "appear as so many nuclei, about which is arranged a very curiously diversified series of highly-inclined strata of a kind of slate"†.

The next notice is that of Sir Henry De la Beche, in a paper read to this Society in 1823. He separates the "trap" and "grey-wacke" rocks of St. David's, and is inclined to regard the trap as "having been forcibly intruded amongst the other rocks at a period subsequent to their consolidation"‡. The areas respectively

\* Since this was written I have made a second visit to St. David's, accompanied by my colleague Mr. W. Topley, of the Geological Survey of England and Wales, with the object of collecting additional material for the second part of the present paper. I have thus been able fully to confirm the conclusions arrived at on the first occasion, and to obtain some additional evidence in the same direction. But nearly the whole of the data bearing upon the question of the existence of Pre-Cambrian rocks were collected in company with Mr. Peach; and the first part of the paper had been prepared before my second excursion.

† Trans. Geol. Soc. ser. 1, vol. ii. p. 79 (1814).

‡ Trans. Geol. Soc. ser. 2, vol. ii. p. 2 (note).



occupied by the two kinds of rock are depicted on the geological map of South Pembrokeshire accompanying this memoir.

In the 'Silurian System' (1839) Sir Roderick Murchison inserted a brief description of the trap-rocks of Pembrokeshire, in which he spoke of them as consisting of two classes, "viz., stratified masses alternating with sedimentary deposits, and amorphous masses which have burst through the strata." Among the older trap-rocks he distinguished "thick-bedded coarse felspathic conglomerates, containing fragments of schist and slate, which range from north-east to south-west in allinement with the other ridges of amorphous trap." These words would seem to imply that he had recognized the presence of true tuffs or fragmental igneous rocks in that region. He also noticed proofs of the intrusive character of some of the amorphous masses; for in the district of Roche Castle, Trefgarn, and Ambleston he found that "the intrusion of this [igneous] rock has produced a powerful effect upon the adjacent strata, particularly on those masses inclosed between the forks of trap in the gorge of the river at Trefgarn, where the red and green sandstones are converted into a brittle, siliceous substance resembling the ribbon jasper of mineralogists" (pp. 401, 402)\*.

In the first volume of the 'Memoirs of the Geological Survey of Great Britain,' De la Beche makes further reference to the geology of Pembrokeshire, and in particular to some of the rocks which have been the subject of more recent discussion. He refers to the rock of Roche and adjoining districts as illustrating the remarkable varieties of texture assumed by the same mass of igneous rock; and he cites the granite between St. Lawrence and Brawdy, a few miles to the east of St. David's, as presenting along its margin a fine-grained variety, like a Cornish elvan, owing to more rapid cooling, and as "certainly seeming to have altered the stratified rocks in contact with it in many places"†.

The Geological Survey of the St. David's district was begun as far back as the year 1842, by Sir A. C. Ramsay, soon after he joined the service. The Map was published in 1845, and was followed by a sheet of Horizontal Sections across the district‡. In these publications all the igneous rocks are included in one colour (green). But in the Horizontal Section the belt of country so coloured, extending (on the map) from the sea at Porth-lisky to beyond Llanhowell, is stated to be composed of "trap, in its strike of various structure,—syenitic greenstone and felspathic volcanic ash"§.

\* The intrusive nature of the Trefgarn rocks was shown by Murchison in 1836 (Proc. Geol. Soc. vol. ii. p. 229). These rocks are included by Dr. Hicks in his "Arvonian" group.

† Mem. Geol. Survey. vol. i. p. 230 (1846). The belt of rocks here referred to has been mapped by Dr. Hicks as belonging mainly to his "Dimetian," but partly to his "Arvonian" group. Quart. Journ. Geol. Soc. vol. xxxv. p. 287 (1879).

‡ Sheet 40 of the Geological Survey Map of England and Wales, and Sheet 1 of the Horizontal Sections.

§ Sir A. C. Ramsay's field-maps, preserved among the official records of the Survey, show that he not only recognized marked differences among the igneous rocks, but that he mapped out the more important varieties. A MS. report

A second (revised) edition of the Map was published in 1857, and was soon followed by a second edition of the Sections. The primary object in the revision of the work was the tracing of a line for the base of the Lingula-flags; but the opportunity was also used for separating some of the more important varieties among the igneous rocks. These were now classed as "syenite" and "greenstone," all mention of the "volcanic ash" of the previous edition being omitted from the St. David's area. A considerable tract to the west of St. David's, which had been mapped by Ramsay as igneous rock, and which was regarded by him as composed mainly of volcanic ash, was now coloured as "altered Cambrian"\*.

As thus revised, the Map showed a long strip of syenite and felsite, stretching from the sea through St. David's in a north-easterly direction for about seven miles, flanked on the south-east by Cambrian strata, and on the north-west by "altered Cambrian" rocks through which long parallel sheets of greenstone had been erupted. The existence of abundant contemporaneous igneous rocks further north and east is clearly shown on the map; but in the immediate

drawn up by him at the time, but never published, has fortunately been also preserved. From this interesting document a few extracts may here be appropriate:—"The igneous rocks of North Pembrokeshire are both intrusive and contemporaneous; the latter, however, occupy by far the greater area. The greatest intrusive mass is that which from Ramsay Sound stretches in a north-easterly direction nearly eleven miles. The best evidence of this trap being intrusive may be seen on the coast near St. David's, at Ogof-llesugn, where it cuts through the strata...at right angles to the line of strike.

"The apparent composition of this large mass is very various, resulting, no doubt, in many instances from the different circumstances under which it cooled and consolidated. Thus, on the east side of Porth Lisky, and on both sides of the Allan at St. David's, it is a large-grained, coarsely crystallized syenite, hornblende being comparatively sparingly diffused throughout. At Porth Lisky granular crystals of quartz are largely developed. In other places the same development may be seen.

"The coast of Porth Lisky is almost entirely composed of volcanic ash, which, being of a softer texture than the traps on the E. and W. sides of the bay, has yielded to the action of the waves, and thus formed a little harbour. ... From hence, in the direction of Ramsay Sound, the rocks are composed of hard siliceous trap [and] various greenstones. ... These frequently alternate with partial layers of volcanic ash. These varieties constitute the rest of the mass to the eastward, without any very apparent order in the manner of their distribution. ... Near Trelethin (St. David's) and elsewhere there is a little volcanic conglomerate. With the exception already mentioned, the strike of the strata generally more or less conforms to the general run of the intrusive mass.

"A glance at the contemporaneous traps shows that volcanic agencies had been in operation for long successive periods. ... From the intermixture of volcanic ash and greenstone at Porth Lisky, it would appear that the formation of this mass was in some measure the work of successive eruptions."

\* Professor Ramsay, as Local Director of the Survey, agreed to this change, which was made on the ground by Mr. Aveline. In many respects the map was a marked improvement upon the first edition; but the suppression of the reference to fragmental volcanic rocks and the introduction of the term "altered Cambrian" were unfortunate changes, one effect of which has been to obscure the fact that to Ramsay belongs the merit of having first clearly recognized the presence of truly contemporaneous fragmental volcanic rocks in a formation of such high antiquity.

vicinity of St. David's all the rocks of igneous origin are represented as intrusive.

Until the year 1864 this interpretation of the structure of the district appears to have remained unchallenged. At the meeting of the British Association in that year, however, a suggestion was thrown out by the late J. W. Salter that the syenitic belt of the Survey was a portion of Pre-Cambrian land\*. The only grounds given for this suggestion were that the rock is syenitic, and that it does not penetrate the overlying Cambrian strata. Next year Mr. Salter, acknowledging himself to have been mistaken, stated that Dr. Hicks had found portions of schist entangled in the syenite, as well as altered strata on the south side of the latter rock†.

In the year 1871 appeared a joint paper by the late Professor Harkness and Dr. Hicks on the "Ancient Rocks of St. David's Promontory"‡. A foot-note in this paper contains an announcement by Dr. Hicks that he had subsequently found on the ridge of St. David's evidence of bedding in its component rocks, and that, as the strike is discordant to that of the Cambrian strata, there must be here a more ancient group of rocks than the Cambrian, occupying a position equivalent to that of the Laurentian group of Canada.

In 1875 Dr. Hicks asserts more confidently the Pre-Cambrian age of the rocks of this ridge, denies that these rocks are syenite as coloured by the Geological Survey, but maintains that they are bedded rocks—quartz-conglomerates and dark-green shales, partly metamorphosed,—and affirms that they are covered unconformably by the Cambrian series§.

Returning to the subject two years later, Dr. Hicks showed a still wider divergence from his original opinion. He now states that he can recognize two distinct series of Pre-Cambrian rocks at St. David's, giving the name "Dimetian" to what he supposes to be the older, and "Pebidian" to the younger series. Discarding the identification of any part of these rocks with syenite, he describes the "Dimetian" as composed chiefly of compact quartz-schists, chloritic schists, and indurated shales, and the "Pebidian" as consisting mainly of indurated shales, often porcellanitic in character. He regards the "Pebidian" as resting unconformably upon and partly derived from the waste of the "Dimetian" rocks. The Cambrian beds are stated to lie unconformably on both these series and to contain abundant fragments of them||. A little later Dr.

\* Rep. Brit. Assoc. for 1864, Sections, p. 64; Geol. Mag. vol. i. p. 289. The Rev. W. S. Symonds, however, claims to have first suggested to Salter a Pre-Cambrian origin for the St. David's rock. See his 'Records of the Rocks,' p. 31, 1872.

† Geol. Mag. vol. ii. p. 430.

‡ Quart. Journ. Geol. Soc. vol. xxvii. p. 384. For the introduction of bedding into the crystalline rocks of the ridge, as expressed in this paper, Professor Harkness does not appear to have been directly responsible. See footnote on p. 387 above referred to.

§ Quart. Journ. Geol. Soc. vol. xxxi. p. 167.

|| Quart. Journ. Geol. Soc. vol. xxxiii. p. 229 (1877).



Hicks recognizes that his "Pebidian" series is in great part made up of volcanic tuffs and agglomerates\*.

In 1878 the late Mr. E. B. Tawney, who, in company with Professor Hughes and Mr. Hudleston, went over the St. David's district under Dr. Hicks's personal guidance, gave an interesting and valuable description of the rocks, to which I shall have occasion to make repeated reference in the sequel. In this paper he accepts generally Dr. Hicks's conclusions, but, though classing the crystalline rock of the axis as metamorphic, confesses that "over a portion of the area, at any rate, it did not show evident bedding enough to prevent our classing it as a massive crystalline rock"†.

In the same year, Dr. Hicks announces the discovery of what he terms a new group of Pre-Cambrian rocks, named by him "Arvonian"‡, consisting of "breccias, hälleflintas, and quartz-felsites," previously included by him in his "Dimetian and Pebidian," but now regarded as intermediate between them, and unconformable with both. In later papers he summarizes the results of his researches§.

During the progress of Dr. Hicks's researches, the rocks of St. David's have been referred to by other writers, sometimes on his authority, sometimes from personal observation under his guidance. It is not necessary to augment this bibliographical outline by citing all such references. Some of them are quoted in subsequent pages, where also several of Dr. Hicks's own papers are dealt with more in detail.

The object of the present communication is twofold,—first to discuss the evidence for the assertion that Pre-Cambrian rocks exist at St. David's, and secondly to lay before the Society an outline of what appears to me to be the true structure and geological history of that district.

## PART I.

The first part of the paper is unavoidably controversial. I propose to examine the evidence for the alleged presence of Pre-Cambrian rocks at St. David's, and to state the facts which, when brought to the notice of geologists, will, I think, be admitted completely to disprove the existence of any such rocks at that locality. Disliking controversy so much as I do, it is with extreme reluctance that I now enter upon it. But I am sure that, in the interest of truth, Dr. Hicks himself, whose published views I must oppose, will be glad that these views should be subjected to the most searching criticism. It is due to him, no less than to my colleagues on the Geological Survey, whose opinions he has controverted, that I should enter

\* *Op. cit.* vol. xxxiv. p. 153 (1878). [Their volcanic origin appears to have been first pointed out to him by Mr. Hudleston.]

† *Proc. Bristol Nat. Soc.* new ser. vol. ii. part ii. p. 121.

‡ *Rep. Brit. Assoc. for 1878*, p. 536; *Quart. Journ. Geol. Soc.* vol. xxxv. p. 285 (1879).

§ *Popular Science Review*, N. S. vol. v. p. 289 (1881); *Proc. Geol. Assoc.* vol. vii. pt. i. p. 59 (1881).



into the fullest details. In the discussion of the subject I am mainly desirous to get at the truth; and I feel confident that my natural and, I hope, laudable pride in the work done by my predecessors and colleagues on the Geological Survey will not lead me for a moment to forget the signal services rendered to the history of the Cambrian rocks by Dr. Hicks, which no one can more cordially recognize than I do.

At the outset I may allude to a characteristic feature in the literature of the subject. From the brief summary above given of the various papers which have appeared, it will be clear that the views at present entertained regarding the Pre-Cambrian age and metamorphic character of the rocks of St. David's are the result of a process of development during a course of years. Dr. Hicks at first put forward the idea of Pre-Cambrianism somewhat vaguely and timidly; but each successive communication from him has shown increasing boldness in the enunciation and extension of his doctrine. Though interesting in itself, this evolution of opinion has been attended with the disadvantage that so many of the statements and views expressed in the earlier papers have since been tacitly modified or abandoned in the later ones, that it is difficult to know how far these earlier publications are available for citation as expressing Dr. Hicks's ultimate opinions. Indeed they appear to possess little more than an historical value, as records of the successive stages through which their author's present convictions have been reached. I shall only cite them where their observations are not positively contradicted in his later memoirs.

It will be most convenient to discuss *seriatim* each of the three alleged Pre-Cambrian groups at St. David's, beginning with the oldest. This, moreover, is nearly the order in which my investigations in the field were conducted.

### 1. "DIMETIAN."

Immediately to the south of St. David's a gentle ridge, roughened here and there with rocky prominences, stretches in a south-westerly direction for rather less than two miles. Its component rock is seen in scattered knobs, but in no continuous section, until, at its seaward termination, from the bay of Porth-lisky eastwards for about half a mile, it forms a rocky shore. This coast-section is the only continuous exposure of the rock in the district. But laying that rock bare as it does, both in horizontal ledges and vertical cliffs, and revealing its contact with the adjacent strata, this coast-section affords the geologist every facility for determining the structure and stratigraphical relations of the rock that forms the ridge.

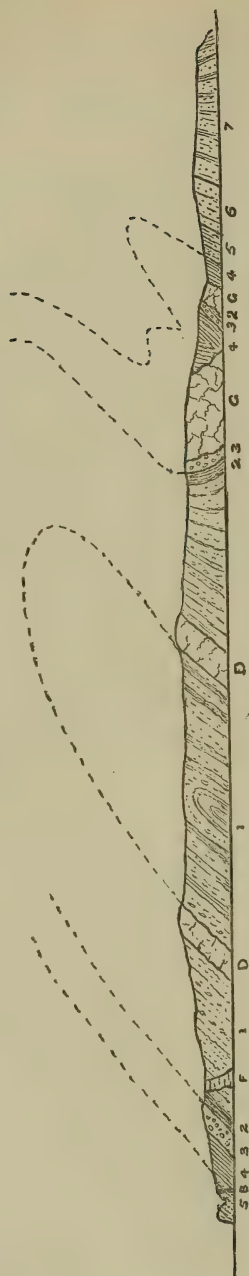
In the original work of De la Beche, and in the subsequent investigations of the Geological Survey, the rock in question was regarded as eruptive, and as later in date than the Cambrian strata, through which it was believed to have been intruded. At the time when these observations were made, the study of petrography was in a sadly neglected state in this country. We must not, therefore, ex-

*Diagrammatic Sections illustrating the Geology of St. David's.*

W.N.W.

E.S.E.

Fig. 1.—Section from near Castell to Porth-clais.



N.W.

S.E.

Fig. 2.—Section from Porth-seli to Cliffs near Nun's Chapel.



For explanation of numbers and letters see Map, Plate VIII.







pect precision or accuracy in the determination of rocks then made, either in the Survey or out of it. The rock of St. David's was marked down as "Syenite" on the Survey Map and Section; and so it remains up to this hour. But in the present discussion the main fact to be noticed in regard to the Survey mapping is that the rock in question was declared to be an eruptive rock, intrusive in, and therefore later than, Cambrian strata.

In his latest papers Dr. Hicks thus describes the rock in question. "The rocks included under this name [Dimetian] . . . everywhere show more or less distinct lines of bedding, striking from about N.W. to S.E. They vary also, to some extent, in their mineralogical characters, if examined at different points, and have apparently an order of succession in which these changes occur at recognisable horizons. The prevailing rocks in this group are of a granitoid character, usually of rather a massive, but sometimes of a schistose nature.

"Sometimes almost pure quartzites are found; but by far the largest proportion contain an admixture of felspar of a white or pinkish colour. Specks of viridite usually occur more or less throughout, and sometimes give quite a tinge to the rock. Mica occurs sparingly, for the most part; but there are occasionally micaceous, chloritic, impure limestone and serpentinous bands. At some places also, thin, compact, white bands of a more highly feldspathic character occur. Some of the beds assume a brecciated appearance, the masses being generally angular or subangular, and in composition much like the associated rocks.

"Speaking generally, the majority of the rocks comprising this group are highly quartzose, of a granitoid or rather massively gneissic nature, and usually easily recognisable by these characters; their strike is about from N.W. to S.E."\*

"This formation [Dimetian] consists chiefly of highly crystalline gneissic rocks, the prevailing types, however, being the so-called granitoid rocks, made up largely of quartz with some pinkish or white felspar. Hornblende is much less abundant than in the Lewisian rocks; but mica is more frequently met with. It may be said to consist chiefly of acid types of rocks, whilst the former is made up mainly of basic types. Bands of limestone, hornblende, chlorite and micaceous schists occur occasionally in this formation"†.

These rocks are regarded by Dr. Hicks as a great, bedded, metamorphic Pre-Cambrian series, later in age than the ancient gneiss of the Hebrides. They are subdivided by him into two groups—a lower, consisting of "the massive granitoid and gneissose rocks of Bryn-y-Garn, St. Davids," and an upper, composed of "the so-called quartz-schists of Porth-lisky"‡.

\* Proc. Geol. Assoc. vol. vii. no. i. p. 61 (1881). On the next page the "Dimetian" rocks are asserted to be "chiefly of elastic origin."

† Popular Science Review, N. S. vol. v. p. 291 (1881). It is to be noted that this paragraph relates to "Dimetian" rocks generally, and is not intended to apply specially to those of St. David's.

‡ Popular Science Review, *loc. cit.*

In reading Dr. Hicks's papers I have been unable to find descriptions of, or references to, the numerous natural sections where the relations of the crystalline rock of the ridge to the surrounding mineral masses are displayed. He states, indeed, that the rock is unconformably overlain by all later formations, but he does not mention any localities where he has observed this unconformability. In one passage he speaks of the Cambrian conglomerates resting immediately on the "Dimetian" rocks, at the bend in Porth-clais valley, and of higher Cambrian beds in a similar position in the harbour\*. It would be more correct to say that the "Dimetian" rock rests there on the conglomerate, as I shall afterwards point out. In another paper he states that "the junction of the Arvonian with the Dimetian may be seen at St. David's, about a quarter of a mile to the south of the Cathedral, and near Rock House"†. But he immediately adds that a slight depression probably marks a fault at that locality. Mr. Peach and I found on examination no evidence of any fault, nor of any line of demarcation between two formations. I shall have occasion to refer to this locality in a later part of the present paper.

Dr. Hicks, in his various memoirs, introduces many lines of fault, of which, after diligent search, we could discover no trace on the ground, and which, for a clear understanding of the structure of the district, are not required‡.

An unconformability is so important a fact in the geological history of a region, that the most convincing proof of it ought to be demanded. We are entitled to expect that, unless where it is too clear to be mistaken, every available fragment of evidence regarding it should be produced. Still more must this expectation be fulfilled where the rocks in question have been greatly disturbed. No one who has not practically tried it can realize the difficulty of the problem to determine whether or not an unconformability exists between two groups of rocks both of which have been intensely plicated or fractured. But to this difficulty no allusion is to be found in Dr. Hicks's papers.

Mr Peach and I began our work by an examination of the ridge of which Bryn-y-Garn is the crest. We were unable to detect anywhere a trace of a structure which had the remotest resemblance to the foliation of gneiss or schist. Nor could we discover in the mass any alternations of other rocks. On the contrary, it everywhere retained the same general aspect, and presented all the familiar external characters of a massive eruptive rock. The presence of gneissic structure and intercalations of schistose bands, however, had

\* Quart. Journ. Geol. Soc. vol. xxxiii. p. 231 (1877).

† Quart. Journ. Geol. Soc. vol. xxxv. p. 289 (1879).

‡ In his map published in 1877 (Quart. Journ. Geol. Soc. vol. xxxiii. pl. x.) Dr. Hicks represents a fault at every locality where the junction of the "Dimetian" with the other rocks is actually visible. These supposed faults have been introduced owing to a mistaken notion of the structure of the ground, and are not required even on the theory to support which they have been invoked.

been so confidently and constantly affirmed that, for a time, we were inclined to believe we had missed the proper exposures. It was not until we had diligently hammered every knob and boss of rock in the whole district, without discovering any other structure than that of an eruptive mass, that we were driven to abandon as entirely imaginary the idea of a bedded structure and metamorphic origin for the central rock of the ridge. The comparatively limited and disconnected sections of the interior amply suffice to make this quite clear. But the admirable continuous sections of the coast-line reveal the structure of the rock so completely that one could not but ask oneself the question many times a day, how such a rock could ever, by any possible stretch of the imagination, be credited with a bedded structure and a metamorphic origin. Cut at all angles by the sinuosities of the coast-line, it can be studied foot by foot across its entire breadth. Did it, therefore, possess foliation of any kind, or were it made up of parallel bands of different lithological characters, such a structure could not possibly escape notice. After the most careful search, however, neither my companion nor myself could discover any thing of the sort. But for the published statements regarding the rock, we should never have thought of making any such search; for the first few exposures would have sufficed to mark it out as unquestionably an eruptive mass.

The petrographical characters of this rock will be given in Part II. of this paper (p. 313). To the naked eye it appears everywhere to be thoroughly crystalline and granitic in structure, like a granite of medium grain, perfectly amorphous, without any trace of ground-mass or any approach to foliation. It can readily be seen to be composed mainly of a granular crystalline aggregate of quartz and felspar with abundant minute black or dark-green specks, which, by their decomposition, give rise to a diffused greenish discoloration. These dark specks were regarded by the Geological Survey as hornblende; and hence, according to the old nomenclature, the rock was termed a syenite. On the other hand, were these dark green specks shown to be a mica, there could be no hesitation in classing the rock as a variety of granite. Whether examined in mass, in hand-specimens, or under the microscope, it presents the ordinary structure of a granite. I shall therefore speak of it simply as a granite, and leave its peculiarities of composition to be discussed in the sequel. I may here mention, in passing, that I have examined microscopically a large series of slices of the rocks of St. David's, and that the result of this examination will be given in Part II. (as previously stated).

The numerous rocky bosses upon the ridge south-west from St. David's, and still more the long coast-section from Porth-lisky eastward, everywhere present a massive rock entirely destitute of definite structure, but traversed by irregular joints, which divide it into blocks, as in any ordinary granite. Here and there by a dominant set of joints it is separated into rudely parallel beds, or even thin slabs, as at Porth-lisky and eastward, where one series of joints, running from N.N.E. to S.S.W. with a high inclination,



gives, at a distance, a deceptive resemblance to bedding. This resemblance, however, disappears on examination.

Numerous other systems of similar joints cut through the mass, precisely as they do through any eruptive crystalline rock. But nowhere have they the character of the divisional planes of a foliated rock, nor do they correspond with any internal arrangement of the component materials in parallel folia\*.

Dr. Hicks lays stress on the fact that, owing to its tendency to split, the rock cannot be dressed for building- or paving-purposes. He proceeds to generalize this fact into a kind of test "in distinguishing many of the metamorphic rocks from those of igneous origin"†. But surely there is no more familiar structure among the eruptive rocks than their tendency towards multiplied jointing in certain directions. Even in a massive homogeneous granite, where a practised geologist could not detect the least trace of any divisional planes, the quarrymen will at once show him what they call the "reed" of the rock, along which it will break easily, but across which its fracture is less reliable and definite. From this condition every gradation may be traced, especially among the weathered parts, until the rock splits into slabs and might at first be mistaken for a bedded mass.

A tendency to split in a given direction is therefore no necessary indication of bedding, and need have no connexion with foliation. Had the rock of St. David's been one which might be classed with the gneisses and schists, it would certainly have revealed abundant proofs of foliation—that is, of a crystalline arrangement of its component minerals parallel with the general divisional planes of the rock. Dr. Hicks asserts that "traces of foliation are abundant"‡. I can only meet this assertion by the statement that my companion and I searched most carefully every exposure of the rock we could find on the ground, and that I have since examined microscopically a series of specimens taken from all parts of the ridge, without detecting either on the large or the small scale any, even the most distant, approach to a foliated structure. Many eruptive granites exhibit perfect foliation along certain pegmatite veins; but even this structure we failed to detect§.

Between the walls of the joints various decomposition-products

\* It may not be out of place to quote here, in confirmation of our observations, those of Mr. Tawney. He recognized the tendency of the rock at Porthlisky to split into flaggy and rhomboidal pieces, owing to concealed laminae coated with a thin chloritic lining, and was disposed to look on this structure as bedding; but he states that "elsewhere it is difficult to say which divisional planes are dominant or less irregular than the others." (Proc. Bristol Nat. Soc. N. S. vol. ii. pt. ii. p. 117.)

† Geol. Mag. dec. 2, vol. viii. p. 143 (1881).

‡ Geol. Mag. dec. 2, vol. viii. p. 142.

§ Dr. Callaway also could find no trace of foliated structure in the crystalline rock of St. David's, though he searched for it in the principal localities named in Dr. Hicks's papers (Geol. Mag., dec. 2, vol. viii. pp. 94, 237, 1881), and, as he adds, it is not mentioned as existing in any of the microscopic descriptions that have been published of the rock.



have been introduced. Most of these are greenish in colour and more or less earthy in texture. Where the opposite walls have been displaced, slickensided surfaces may be seen upon them and upon the substances interposed between them. But these appearances present no features differing from what are universally found among massive jointed rocks. They cannot be confounded with any original structure of the mass.

Occasionally veins of a paler colour and finer texture ramify through the rock. They vary in width from an inch or less up to more than a foot. Every one familiar with a large mass of granite will recognize such veins at once as characteristic features of it. These also are referred to more in detail in Part II.

The only distinct species of rock which we could discover in the mass is a dull-greenish, more or less decomposing, diabase or wacke, occurring in the form of abundant dykes and veins. These vary from a few inches to several feet in breadth, and traverse the granite irregularly in all directions. Where several run parallel at a short distance from each other, and have a slight hade in the same direction, they produce a deceptive resemblance to an alternation of beds.

That these dark-green rocks, however, are all eruptive, intrusive, and of later date than the granite, may be confidently inferred on the following grounds:—1st. They have precisely the ordinary external forms of eruptive dykes and veins, ramifying in different directions, coalescing and reuniting. 2nd. They present the usual microscopic characters of dykes of diabase or ancient basalt-rocks, with which they agree in crystalline structure, in the presence and linear arrangement of amygdules, in the existence of a rude prismatic structure transverse to the walls, and in their tendency to spheroidal weathering. 3rd. In microscopic structure they unmistakably belong to the basalt family. 4th. They not only traverse the granite (being most abundant in it) but are found cutting through the Cambrian beds on many different horizons. The true character of these eruptive rocks appears to have been first detected by Prof. Judd\*,—a conclusion confirmed by Mr. Tawney†. Dr. Hicks draws a distinction between some of them which he admits to be intrusive and others which he seems disposed to regard as bedded in the "Dimetian" mass‡. But for this distinction I was unable to discover any ground whatever. There can be no question as to their universally intrusive character and late Cambrian or Post-Cambrian date.

In some of his earlier papers Dr. Hicks refers to the occurrence of abundant shales among the more crystalline rocks of the ridge. In his more recent summaries no reference is made to such inter-

\* Quart. Journ. Geol. Soc. vol. xxxiii. p. 235 (1877), and xxxiv. p. 156 (1878).

† Proc. Brist. Nat. Soc., new ser. vol. ii. pt. 2, pp. 113 *et seq.*

‡ Quart. Journ. Geol. Soc. vol. xxxiv. p. 156. In his more recent papers he omits mention of these rocks as integral parts of his "Dimetian" series, unless they are included in the "hornblende and chloritic schist," which he states to be also a portion of the same series.

calations, though the occasional occurrence of micaceous and chloritic schists is referred to. I have been unable to determine what portions of the mass of rock at St. David's could have been regarded by him as stratified or foliated intercalations of any kind. I believe him to have been deceived sometimes by the greenish decayed material filling up the partially opened joints, sometimes by the diabase dykes and veins. He appears also to have included in his "Dimetian" group portions of the undoubtedly bedded rocks (quartzschists, quartzites, shales, &c.) which flank the massive rock of the ridge, as will be shown in the subsequent description of the coast-section at Porth-lisky. I repeat in the most emphatic manner that, after an exhaustive search over the whole ridge in question, neither Mr. Peach nor I could find the slightest trace of any shale, schist, quartzite, gneiss, or other stratified rock, bedded with that composing the ridge between Bryn-y-garn and the headlands south of Porth-lisky—nor of bedding or definite structure of any kind, save the joints universally present in similar massive rocks. We cannot even conjecture on what grounds the assertion has been so often made that the central part of the ridge is bedded, and that its bedding has an invariable strike from N.W. to S.E. We could see absolutely nothing in the rock to afford any basis for such a statement\*.

Did no other than petrographical characters exist to guide us, these are so clear in their concurrent testimony that there could be no doubt as to the propriety of placing the rock in question among the granites. It has the usual typical features of a granite, and none of those of a schistose rock.

But further evidence is abundantly available. That this rock is not only a granite but one which has been erupted through the Cambrian strata, and must therefore be younger than they, is admirably demonstrated by the way in which it behaves to the rocks that surround it. A field-geologist naturally turns at once to the line of junction between two rock-masses to ascertain their mutual relations. Unfortunately, in most cases such a line is so much obscured by superficial deposits that the actual contact of the rocks can, at the best, be seen only to a limited extent and in few places. At St. David's, however, the coast-section and the transverse valley cut by the river Allan permit the actual junction of the granite with the surrounding rocks to be seen at several localities and on both sides. I have searched in vain among the published papers for any account of these localities. It is difficult to believe that they can have been actually seen by any one who could afterwards maintain the rock to be Pre-Cambrian in age and metamorphic in origin†. They show the granite to be unmistakably

\* On the occasion of my second visit to St. David's I again sought, with Mr. Topley, for any trace of foliation or bedding in the crystalline rock of the ridge, but equally without success.

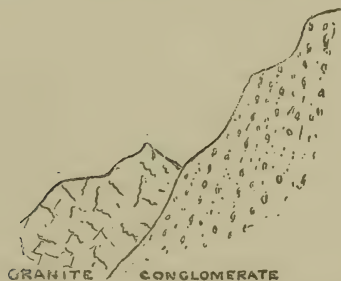
† It appears that Dr. Hicks started with the idea expressed on the Geological Survey map that the crystalline rock of the St. David's ridge is intrusive. He afterwards wrote that "on further examination it seemed clear that the syenite

eruptive; for the strata adjacent to it present examples of the induration and silicification so commonly, though not universally, observable along the borders of a granite boss.

In describing the sections that exhibit the actual contact of the eruptive and sedimentary rocks, I would first allude to a fact of some importance which hitherto appears to have escaped notice. In the course of my examination my colleague and I observed that as it crosses the valley of the Allan above Porth-lisky, the granite sends out a tongue-like projection across the river at the ford, and that this projection is separated, by an intervening mass of Cambrian shales and sandstones, from another projecting tongue of granite lying further north. This northern portion may cross the river as a narrow belt and thereby connect the main mass of Bryn-y-garn with the lesser area that extends to Porth-lisky. As it contracts, however, to a breadth of not more than eighty yards on the west side of the Allan, there seems to be hardly any room for it to pass across the valley. Though, no doubt, continuous underneath, the granite mass is probably divided at the present surface into two separate areas by intervening Cambrian strata. (See Map, Plate VIII. p. 268.)

The Bryn-y-garn granite mass projects for a few yards into the Cambrian grits and shales on the right bank of the Allan. I had several yards of the actual contact of the rocks laid bare at the foot of the hill, and found that the granite distinctly overlies the grit (fig. 3.).

Fig. 3.—*Section of Junction of Granite with Cambrian Strata.  
Right bank of Allan River, Porth-clais.*



the line of junction being a wavy surface inclined at an angle of about  $55^{\circ}$  \*. The grits are much indurated; and their bedding is

did not penetrate any of these beds" (Quart. Journ. Geol. Soc. vol. xxxiii. p. 229, 1877). I cannot conceive in what direction this further examination was carried, nor how the very clear proofs of intrusion could have been missed or misunderstood.

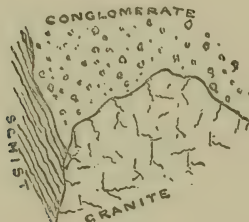
\* This junction was bared, with Mr. Topley's assistance, on the occasion of my second visit. Some portions of this grit are so coarse as to pass into a quartzose conglomerate, which may be the conglomerate band above the volcanic group. This is about the place where that band should come in, next the green and red beds seen at Porth-clais. Its position is suggested in Section fig. 1, p. 268.

obliterated, though lines of pebbles can be traced which appear to indicate that the strata are nearly vertical.

On the opposite side of the river another junction of the granite with the Cambrian beds can be seen. The latter consist of greenish shales and sandstones dipping N. 20 W. at  $55^{\circ}$ , and are here again distinctly overlain by the granite, which cuts across the edges of the strata that dip beneath it. At this point the line of junction has served as a channel for percolating water; and the rocks on either side are so decomposed that no satisfactory observations of their internal characters can be made.

It is deserving of remark that, in its course across the valley, the projecting tongue of granite now described traverses obliquely a considerable thickness of strata. In particular, it can be seen to have cut out nearly the whole of the thick bed of grit above referred to, no portion of which appears on the opposite side (figs. 4 and 5).

Fig. 4.—*Plan of Junction of Granite with Cambrian Strata, Porth-clais.*



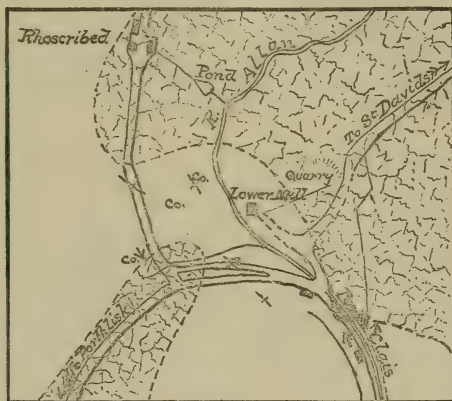
The eastward prolongation of the Porth-lisky granite mass likewise protrudes as a tongue into the Allan valley. This tongue has a breadth of about eighty yards; but it seems to be narrowing eastwards, so that, as already stated, it probably does not cross the valley. On both its northern and southern borders its junction with the Cambrian rocks can be seen. On the south side greenish sandstones, shales, and silky hydro-mica schists, like some of those to be afterwards referred to as occurring at Porth-lisky, abut against the granite; but the rocks along the line of contact have been decomposed into clay by the rise of water. On the north side the junction is more satisfactorily shown in a quarry on the left side of the road from Porth-clais to Rhoscribed. Here the conglomerate, in highly inclined beds, is overlain by the granite, which leans against it. The conglomerate is indurated; but at the actual contact both rocks have been much decomposed by percolating water. Some of the details of these junctions of the granite with the stratified rocks are reserved for the second part of this paper (p. 317).

Before leaving the relations of the granite to the Cambrian strata in the Allan valley, I must allude to the fact that this is the locality cited by Dr. Hicks as showing the Cambrian conglomerates and



higher beds resting on his "Dimetian" ridge\*. At every section, instead of lying upon the granite unconformably, they plunge beneath it. The general disposition of the rocks in this part of the valley is expressed in the accompanying diagram (fig. 5). It will

Fig. 5.—*Sketch Plan of the Disposition of the Rocks in the Allan Valley at Porth-clais.*



be evident from this map and from the foregoing description that the relative positions of the two rocks cannot be accounted for by faulting†. At Porth-clais the actual terminal curve of the granite projection can be traced across the bed of grit through which it has risen (fig. 4). These junctions are characteristically those of an eruptive mass.

But the most important junction of the granite and Cambrian beds is that which has been cut by the sea in the range of cliffs between Porth-lisky and Porth-clais at the little inlet of Ogof-llesugn (fig. 6). The granite, which extends continuously eastward from Porth-lisky, abruptly ends off, and is succeeded at once by vertical sandstones and shales, which are truncated by it nearly at a right angle‡. On the seaward face of the cliff the granite has

\* Quart. Journ. Geol. Soc. vol. xxxiii. p. 231 (1877).

† That there may have been some local slipping along the boundary-line between the granite and the rocks it has invaded is not unlikely. In the Allan valley the faults would need to be reversed ones, and to wind about so as precisely to counterfeit the boundary-line of an eruptive rock. This subject is further referred to in Part II. (p. 310).

‡ This locality is referred to by Dr. Hicks as a line of fault; indeed, in his map (Quart. Journ. Geol. Soc. vol. xxxi. pl. viii.), as already stated, he makes the boundary-line between the two rocks everywhere a fault. I have admitted that, along the flanks of the granite, occasional local slips may have taken place; but the visible sections prove that no continuous or important faults occur there. Possibly some slight displacement may have taken place at Ogof-llesugn; but the mass of conglomerate is imbedded in the granite. It should be noted here that the section described in the text is the same as that already referred to in the citation from Sir A. C. Ramsay's early MS. report as affording the best evidence of the intrusive nature of the igneous rock.

torn off a mass of conglomerate and associated tuffs. These rocks have been so intensely indurated and silicified that the quartz pebbles are hardly traceable on a fresh fracture, though they project more evidently from a weathered surface. It is even difficult in places to say precisely where the line between granite and conglomerate should be drawn, so intimately are they welded together. The former rock, still presenting its normal petrographical characters, may be seen both underlying and overlying the involved portions of conglomerate, red shale, and fine tuff, the latter being altered into a kind of hornfels or porcellanite. Veins of granite penetrate these altered rocks. Great numbers of diabase dykes traverse the granite; and some of them cut the Cambrian strata also.

Fig. 6.—*Plan of Junction of Granite with Cambrian Strata, Ogof-ll'esugn, St. David's.*



The importance of this section in any discussion as to the nature of the crystalline rock of the ridge south of St. David's cannot be exaggerated. It is rather difficult of access, which may possibly account for the absence of any description of it in the papers hitherto published; but it completes the demonstration that the rock, which can be traced from St. David's to the coast south of Porth-lisky, is an eruptive mass that has been intruded into the Cambrian strata. The quartz conglomerate, here altered by the granite, is unquestionably the same band which can be traced along the coast for fully two miles eastward, and the greenish and reddish tuffaceous shales are recognizably those that everywhere accompany the conglomerate.

On the opposite side of this portion of the granite ridge the eruptive mass comes into contact with the stratified rocks in the Bay of Porth-lisky. Unfortunately, however, the actual junction is obscured, on the cliffs by the decomposition of the schists that abut on the granite\*, and on the beach by the quantity of fallen blocks.

The condition of the beach doubtless varies from time to time; but neither on the occasion of my first visit last September, nor on the second examination five months later, could I trace the actual contact of the two kinds of rock, though I followed them to within a few feet of each other. The schists are, in some bands, much indurated, passing into a kind of quartzite or quartz schist. The crystalline rock of the ridge, as exposed along the cliff, presents

\* There may have been a shift at the line of junction here.

features not unfrequently observable along the edge of the granite, being fine-grained and of a diffused greenish tint. On the beach it becomes in places very quartzose and much impregnated with calcite, some portions weathering with a nodular surface not unlike that of a conglomerate. Possibly there may be some dislocation along the line of junction, and the calcareous portions may be due to infiltration along the lines of fracture\*. Though I searched the locality very carefully with Mr. Peach, and subsequently with Mr. Topley, I could not trace bedding in the granite such as has been described by Dr. Hicks. As already mentioned, the granite is much jointed here, and the joints are in some places close and rudely parallel; but they are mere joints, readily distinguishable from any original structure of the rock.

It is worthy of remark that the schists which abut on the granite, and extend across the Bay of Porth-lisky, dip at high angles towards N.N.W. They strike at the granite, so that, apparently, lower beds come out as they are followed seawards. I shall afterwards show that all these strata are inverted, and that, consequently, the most easterly beds at Porth-lisky are stratigraphically higher than those immediately to the west of them. Mr. Peach and I observed these peculiar schists at Ramsey Sound lying below the conglomerate; indeed, if the rocks of Porth-lisky could be traced for a quarter of a mile further out to sea, the conglomerate would doubtless make its appearance†.

If now we turn to the Map (Pl. VIII., p. 268), it will be seen that the granite, in its course from St. David's to the sea, cuts across successive horizons of Cambrian beds, penetrating deepest into them on the north and east, and reaching its highest platform on the south. The way in which it has broken through and pushed aside the conglomerate is peculiarly striking. That band of rock has been assumed by Dr. Hicks to be the base of his Cambrian system; we find, however, that the granite not only invades it, but ascends across the overlying shales and sandstones.

One further statement calls for notice here. Dr. Hicks, having satisfied himself that the granite of St. David's is a bedded metamorphic rock, has ventured upon estimates of its thickness; in his paper of May 1878, he remarks that the thickness previously claimed by him for his "Dimetian" group, *viz.* 15,000 feet, is not an over-estimate‡. But, as will be afterwards pointed out, the only bedded rocks that occur between St. David's and Porth-lisky lie on the flanks of the granite, and strike with the ridge instead of across it,

\* Mr. Tawney, who had the advantage of being guided over the locality by Dr. Hicks himself, regarded the calcareous bands as "due to the decomposition caused by water filtering down joints, removing alkaline silicates, and depositing carbonates of lime and magnesia" (Proc. Bristol Nat. Soc. N. S. vol. ii. pt. 2, p. 116). I cannot doubt that this is the true explanation of the limestone and dolomite bands described by Dr. Hicks from this locality.

† In connexion with this southward prolongation of the conglomerate, we must look on the mass at Ogof-llesugn as having been torn off from the main body, which must lie somewhere beneath the granite.

‡ Quart. Journ. Geol. Soc. vol. xxxiv. p. 154; see also vol. xxxiii. p. 230 (1877).



so that they must be measured at right angles to the line taken by Dr. Hicks. I am not aware of any method by which we can measure the thickness of a square mile of granite.

To the phenomena of contact-metamorphosis I shall return in the second part of this paper (p. 317). The evidence now brought forward is, I submit, amply sufficient to prove that, whether studied in hand-specimens, in microscopic slices, or in the numerous natural sections which show its geotectonic relations, the "Dimetian" group of Dr. Hicks, instead of being a ridge of Pre-Cambrian metamorphic rock, is really a boss of eruptive granite, later in date than the Cambrian strata through which it has been intruded, and that the term "Dimetian", so far at least as regards its original locality, must be abandoned.

## 2. "ARVONIAN."

The rocks grouped under this name by Dr. Hicks at St. David's are thus described by him.

"The rocks now included in this group I originally associated with the Dimetian; but in the year 1878\* I separated them from the latter, under the above name.

"On the Survey Maps they are coloured generally as felstones and porphyries, usually intrusive amongst Cambrian or Lower Silurian rocks. They consist in reality of flows of rhyolitic lavas, alternating with felsitic breccias and hälleflintas. The strike is from N. to S., and, hence, discordant to those newer rocks with which they are usually surrounded, as also to the underlying Dimetians. Like the Dimetian, this is a highly acid group, being mainly made up of the types of rocks known as the quartzo-felspathic. But, instead of being like these, chiefly of elastic origin, we have here a great series of acid lavas mixed up with a comparatively small proportion only of rocks of a clastic nature. In colour these lavas vary from being very dark (almost black) to a light grey, and from deep red or violet to flesh-colour. The flow-structure is usually well marked, and in many cases the spherulitic structure also. A large number are porphyritic, from the minute crystals of felspar or quartz. The hälleflintas are more siliceous-looking than the rhyolites, and have a horny-looking texture and fracture. Under the microscope they are still more easily distinguishable. Their chief peculiarity, perhaps, consists in the manner in which some of the quartz becomes separated away into nests, so as to give the rock a curious pseudo-porphyritic appearance; whilst the intervening parts exhibit the appearance of a micro-crystalline mass of quartz grains, with intervening felsite. The breccias usually consist of fragments of lavas and hälleflintas, like those in association with them, and the pieces angular.

"This group, therefore, is characterized by being for the most part made up of acid lavas, breccias, and compact siliceous rocks of the hälleflinta type, and as usually having the strike in a direction from N. to S."†.

\* [Quart. Journ. Geol. Soc. vol. xxxv. p. 285 (1879).]

† Proc. Geol. Assoc. vol. vii. no. i. p. 62 (1881).



In the definition of the lithological characters here ascribed to the rocks in question I am disposed generally to agree. These mineral masses are partly eruptive quartz-porphyrries, and partly highly siliceous strata of sedimentary origin to which the names *hállefinta*, *hornfels*, *porcellanite*, *chert*, *Kieselschiefer*, *adinole*, &c. might in different places be applied. But here my agreement ends. Instead of finding evidence that these rocks lie with a discordant strike unconformably against the so-called "Dimetian" below, and are covered unconformably by Cambrian or "Pebidian" beds above, Mr. Peach and I discovered that Dr. Hicks had really created a separate stratigraphical "group" out of the zone of quartz-porphyry bosses and dykes with the accompanying indurated sedimentary rocks that surround the central core of granite.

I shall discuss the phenomena of intrusion and metamorphism in the second part of this paper. There are only two questions that need be considered here. In the first place, Dr. Hicks asserts that his "Arvonian" rocks usually present a north and south strike, and are unconformable to his "Dimetian" group. This assertion has been virtually disproved by the evidence which I have now advanced as to the true nature of what he calls "Dimetian." But, for the sake of precision, I may here state that my colleague and I made careful observations of the strike of the rocks all round the granite, and found the dominant trend to be parallel with the granite ridge—that is, generally in a north-easterly and south-westerly direction. Where the average strike changes, it is rather towards east and west than towards north and south, as is more especially noticeable on the coast between Ogof-llesugn and Caerbwdy. Nowhere could we detect a prevalent north-and-south strike, nor any general tendency in the rocks to strike at the granite.

The quartz porphyries, which appear to constitute a great part of the so-called "Arvonian group," show no strike. They are really as devoid of any semblance of bedding as an eruptive rock can well be. Dr. Hicks remarks that the junction of the "Arvonian" and "Dimetian" rocks is to be seen at St. David's; but he immediately adds that there is a line of fault at the locality between the two groups. He describes the "Arvonian" rocks as "striking up towards the ridge" and "the lowest beds" as being visible near the Deanery. The rocks exposed over that area are of a type not unfrequently observable round the edge of the granite and doubtless connected with it, to which I shall refer more in detail in Part II. They are entirely amorphous, eruptive masses, without the least trace of any kind of bedding. On the road-side between the Deanery and Rock House, among the numerous joints there is one set that runs in a north-and-south direction, the joint-planes being inclined at high angles towards the west. This was the only structure that I could discover which might have suggested the idea of bedding.

In the second place, Dr. Hicks alludes to the view expressed on the Survey Maps that the igneous rocks in question are intrusive, but only to dismiss it without further notice and to substitute for it the statement that "they consist in reality of flows of rhyolitic

lavas, alternating with felsitic breccias and hälleflintas”\*. In another paper he writes that “they were marked on the Geological Survey Maps as intrusive felstones; but a very cursory examination proved that they were not of that nature, and that they were in reality bedded sedimentary rocks which had undergone metamorphic change”†. Passing over the discordance between these two emendations of the Survey Maps, I would observe that the author, in dismissing the view taken by the officers of the Survey and substituting for it another of his own, offers no observations of any kind in support of his emendations. He simply declares the rocks to be rhyolitic lavas (meaning evidently, streams of lava that have flowed out at the surface), but mentions no character by which they are to be distinguished from intrusive masses. In a previous paper, indeed, he had admitted that they were “possibly intrusive”‡, though at the same time he regarded them as “appearing distinctly to lie in the line of bedding of their associated quartz rocks.” He would seem to have been led to regard them finally as lavas, from a remark made to him by Professor Bonney that they most resemble a lava-flow§. I presume it was the presence of fluxion-structure in them that suggested this identification; but I shall subsequently show how fallacious this presumed test is for the purpose of distinguishing the superficial from the more deep-seated manifestations of volcanic matter. To go no further than the region of St. David’s, I find spherulitic structure and fluxion structure in the most obviously intrusive dykes.

In every example in this district where the actual contact of the porphyries with the surrounding stratified rocks can be seen, the porphyries are distinctly intrusive. In the quarries north of the Church Schools the fine tuffs and schists or shales, which are undoubtedly a portion of Dr. Hicks’s “Pebidian” group, are much indurated close to the porphyry, which traverses them obliquely to their bedding. But this alteration insensibly dies away as the strata are followed northward; and at a distance of about sixty or seventy yards they assume their usual characters of fine tuff. The actual intrusion of one of the quartz-porphyries as a dyke or elvan through the strata, however, may be seen in the noble section among the cliffs south of Nun’s Chapel. Other examples occur further west, near Treginnis. The behaviour and structure of these rocks will be discussed in Part II., in connexion with the metamorphism of the district.

Dr. Hicks associates certain breccias with his rhyolites as contemporaneous components of the “Arvonian group.” But there can be no doubt that they are portions of the volcanic (or what he terms his “Pebidian”) group which have been invaded by the porphyries and have been much indurated. They can be seen north of

\* Proc. Geol. Assoc. vol. vii. pt. 1, p. 62 (1881).

† Quart. Journ. Geol. Soc. vol. xxxv. p. 286 (1878).

‡ Quart. Journ. Geol. Soc. vol. xxxiv. p. 153 (1878).

§ Ibid. p. 154.

the Church Schools forming part of that group, also on the south side of the ridge near Nun's Chapel.

So far, therefore, as regards the evidence to be obtained at St. David's itself, there is no foundation whatever for the institution of a separate group under the name of "Arvonian." The rocks so called by Dr. Hicks are portions of his "Pebidian" group invaded and altered by a central core of granite and abundant dykes or bosses of quartz porphyry\*. What the "Pebidian" group really is must now be considered.

### 3. "PEBIDIAN."

The general characters of this group of rocks at St. David's are thus summarized by Dr. Hicks:—

"Most of the rocks in this group differ from those already described, though occasionally there is a certain amount of resemblance remaining. Instead of the acid types prevailing, as in the previously named groups, we find the basic types more largely developed. Basic lavas and breccias now predominate over the rhyolites; and the clastic rocks are more micaceous, chloritic, and talcose. On the Survey Maps these rocks are coloured as altered Cambrian, and partially as intrusive greenstones. On more careful examination the so-called greenstones turn out to be bands of indurated volcanic ashes, and contemporaneous basic lava-flows. Agglomerates and breccias occur in great thicknesses in the group; and the fragments are chiefly, except in the lowest beds, of a basic character. Chloritic, talcose, felspathic and micaceous schistose rocks occur also at various horizons, and occasionally purple and green slates. Serpentinous bands are also sometimes found, as well as veins of jasper, epidote, and asbestos. Some of the finer and more quartzose beds assume a gneissose appearance, and others are porcellanitic.

"The strike in this group is from about N.E. to S.W., and hence nearly in accordance with that in the overlying Cambrian rocks. That this group, however, must have been in much the same condition in which it is found, before a grain of the Cambrian rocks was deposited, is perfectly clear from the fact that the conglomerates at the base of the latter are very largely made up of rolled pebbles and rounded fragments identical with the rocks below. An actual unconformity between the two groups is also seen at several points.

"This group consists of a far more varied series than the two former, and doubtless would exhibit a still greater diversity if fully exposed; for it is perfectly clear that, in consequence of the rapid

\* The intrusive character of the quartz porphyry south of Nun's Chapel is admitted by Dr. Hicks in his paper of 1877 (*Quart. Journ. Geol. Soc.* vol. xxxiii. p. 236). He gives a section showing it cutting through the rocks (his "Pebidian"), and says that it does not penetrate the Cambrian beds above. But at its western end, where it descends to the beach, it approaches the conglomerate, and would probably be found piercing it if the beach could be cleared of the fallen débris. I shall show that this rock is precisely similar in petrographical character to the so-called "Arvonian" porphyries of St. David's (p. 315).



overlapping of the sections by the Cambrian rocks, much is hidden from view" \*.

I accept generally the lithological descriptions here given, but with important modifications to be afterwards stated. There can be no doubt that the group is almost entirely of volcanic origin—formed principally of various tuffs with bands of olivine diabase and occasional intrusive masses of quartz porphyry. I have already shown that the volcanic nature of these rocks was clearly recognized by my predecessor, Sir A. C. Ramsay, in his original map and section, and in his early MS. report on the St. David's area, and that he afterwards allowed this view to be set aside in favour of the opinion that the peculiar bedded rocks on the west side of the granite ridge are altered Cambrian strata through which intrusive "greenstones" have been injected. It is this view which is expressed upon the second and latest edition of the Survey Map and Section. I at once acknowledge that in this respect the present Map and Section are seriously in error, and that Dr. Hicks deserves the thanks of geologists for having, as it were, rediscovered probably the oldest group of palæozoic volcanic masses yet known in this country.

Reserving for the second part of this paper what I have to add to the published descriptions of these rocks, I proceed at once to consider the evidence for their forming a distinct Pre-Cambrian group lying unconformably on the groups below, and covered unconformably by the Cambrian strata above, as has been so repeatedly asserted by Dr. Hicks.

In this instance, again, I have been unable to discover in his published papers references to any sections where the proof of the alleged unconformability between the so-called "Pebidian" and "Arvonian" rocks can be seen. The unconformability, if it existed, might be proved (1) by actual sections showing the line of junction, (2) by detailed mapping of the ground and the detection of proofs of overlap and discordance, or (3) by the evidence of included fragments. Dr. Hicks asserts that "resting unconformably upon the whole [Arvonian Group] are the great agglomerates of Clegyr Hill, the base-beds of the Pebidian, which are made up of masses of Dimetian rocks, of quartz felsites, spherulitic felstones, and hälleflintas, and all in the condition in which they are now found composing the underlying ridges. From this evidence it is tolerably clear that the position of the Arvonian or hälleflinta group is intermediate between the Dimetian and the Pebidian, and that there is, at least in this area, very clear proof of unconformity and hence of lapse of time having intervened" †. In this passage he enumerates two of the three kinds of proof just referred to as indicative of the discordance in question.

Again my companion and I sought diligently for any trace of the alleged evidence, but completely without success. Like the other assertions with which I have been dealing, its groundlessness became more apparent at every step of the investigation. There is not only

\* Proc. Geol. Assoc. vol. vii. p. 63.

† Quart. Journ. Geol. Soc. vol. xxxv. pp. 289, 290 (1879).



no vestige of an unconformability, but the volcanic groups which Dr. Hicks has included in his "Pebidian" can be seen in many places graduating insensibly into the altered shales which form a great part of his so-called "Arvonian." In fact the latter group, as above stated, consists of portions of the volcanic breccias and tuffs (that is, the "Pebidian" strata) where these are invaded by quartz porphyry. This is well seen in the series of quarries north from the Church Schools, where, as already remarked, a perfect graduation can be traced from highly altered shales and tuffs, next the intrusive quartz porphyries, northward into the normal condition of these strata in the district. The assertion that the Pebidian strata are made up chiefly of "Dimetian" fragments must, from the evidence already adduced as to the late date and intrusive nature of the "Dimetian" mass, be founded on error of observation. I need hardly say that, after the most patient search, neither Mr. Peach nor myself could detect anywhere in these tuffs and breccias the smallest fragment which, by the utmost stretch of fancy, could be referred to the granite of the "Dimetian" ridge. There occur indeed, abundant lapilli of felsite, as I shall more fully describe in the sequel; but these fragments can readily be discriminated from the material forming the eruptive porphyry dykes and bosses.

But the most extraordinary statement in the passage just cited is that in which the writer asserts that the great agglomerates of Clegyr Hill rest unconformably upon his "Arvonian" group. The agglomerates in question are well seen on the road-side east of Clegyr Bridge, where they dip towards S.S.E. at  $65^{\circ}$ , and are interbedded with siliceous layers (h  lleflintas). These siliceous bands are precisely the same as those seen near the quartz porphyries north of the Board-Schools, on the shore at Nun's Chapel, and elsewhere. They are characteristic of the volcanic group where it is traversed by intrusive siliceous eruptive rocks, and particularly of a zone that lies not far below the conglomerate to be referred to in a later part of this paper. The presence of these bands in what Dr. Hicks himself cites as typical "Pebidian" agglomerates is an important fact, in still further proving that, at St. David's itself, "Pebidian" and "Arvonian" are only different names for the same series of rocks.

On Clegyr Hill the same agglomerate, interbedded with fine tuff and bands of siliceous schist, and traversed by a dyke or boss of spherulitic quartz porphyry, appears to dip towards the N.W. at  $40^{\circ}$ - $50^{\circ}$ —that is, actually towards the rocks which it is said to overlie. Nothing is seen at the surface for a distance of nearly a quarter of a mile, when the observer finds that a few square yards of quartz porphyry have been laid bare in a quarry to the south of Trepewit, while, about thirty yards distant, fine tuff, nearly vertical, but preserving the normal E.N.E. strike, is seen on the road-side. Yet Dr. Hicks boldly asserts not only that the rocks of Clegyr Hill overlie the porphyry, but that they do so unconformably !

## 4. RELATION OF "PEBIDIAN" TO CAMBRIAN ROCKS.

The unconformability between the top of the "Pebidian" rocks and the conglomerate which Dr. Hicks assumes to be the base of the Cambrian system likewise disappears on examination. As before, he rests upon presumed discordance in the dip and strike of the rocks, and on the alleged presence of fragments of the older rocks in the younger. But both these tests fail him.

In the first place it can be conclusively shown that in dip and strike the volcanic group and the overlying conglomerate, sandstone, and shales are perfectly conformable throughout. Mr. Peach and I proved this by numerous measurements all over the district. We observed that, at the locality on Ramsey Sound, near Castell, mentioned by Dr. Hicks as showing the unconformability of the conglomerate, there has been a slight local disturbance of the strata. The beds below the conglomerate have been bent up, and the conglomerate itself has been pushed over them. Seen from the top of the cliff the conglomerate lies in part on their edges. But when examined on the spot the unconformability disappears, and the strata below the conglomerate are found at a little distance from the disturbance to be perfectly conformable with it. The same complete conformability is well exposed on the face of the next projecting cliff southward.

At another locality, on the coast south of Caer-fai, also referred to by Dr. Hicks, there is an apparent discordance between the conglomerate and the beds below it. But here again the seeming unconformability at once disappears on examination. It is an instance of the familiar phenomenon of what has been called "contemporaneous erosion." Every field-geologist knows that this structure constantly occurs among pebbly strata, from the most recent valley-gravels to the most ancient sedimentary rocks yet known. Were it to be used as indicative of serious unconformability, we might have half a dozen discordant formations in a single gravel-pit. But the section at Caer-fai, as shown in fig. 7, might as well be taken to prove unconformability above the conglomerate as below it. In reality these are merely common local accidents of sedimentation, and, but for their relation to the question now under discussion, would not be worthy of special notice.

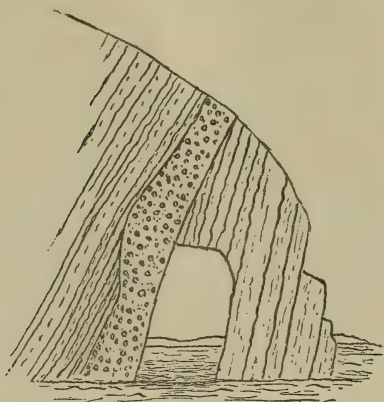
Dr. Hicks, in one of his papers, remarks that "the line of strike of the Cambrian rocks appears at first sight to be nearly identical with that of the underlying Pebidian beds; but when examined carefully it will be seen that in no case is it truly so, but that the conglomerates overlap the beds irregularly and at different points in the succession"\* . In another paper he states that the Cambrian conglomerate overlaps the "Pebidian" group altogether, so as to rest upon the "Dimetian" rocks†.

I was not surprised by these statements when I found that he had wholly missed the structure of the ground between Ramsey Sound and the granite ridge. At first an observer traversing

\* *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 159 (1878).

† *Ibid.* vol. xxxiii. p. 230 (1877).

Fig. 7. *Contemporaneous Erosion accompanying Cambrian Conglomerates. Caer-fai, St. David's\*.*



the coast-section, or looking at the occasional exposures inland, and finding that all the tuffs, breccias, and diabase sheets dip steadily in a north-westerly direction, would infer that he is crossing a continuous succession of beds, the highest being at the north-west end and the lowest at the south-east end of the section. This natural inference has been drawn by Dr. Hicks, and may partly account for some of the errors into which he has fallen. Further comparison, however, would have shown him that the strata are here isoclinally folded; that is, they have been thrown into an anticline, which has been bent over to the south-east, so that the strata in the south-eastern half of the fold are inverted (figs. 1 & 2, p. 268). That this is the case, was proved by Mr. Peach and myself in the identification of the same beds on the two sides of the arch. In particular, the peculiar group of shales or schists immediately below the conglomerate on Ramsey Sound reappears at Porth-lisky. The conglomerate accompanies them; but at the latter locality it has been cut out by the granite. It appears, however, a short way inland in the Allan valley, and on the east side of the granite at Ogof-llesugn. The reversed dip continues along the coast-line; but the beds are eventually seen to right themselves, and they appear in normal order to the east of Caer-fai. I shall return to this interesting structure in the second part of this paper (p. 309)†.

\* Dr. Hicks figures this junction as an unconformability of the Cambrian conglomerates on the Peibidian Beds. But he reverses the visible dip, making the rocks inclined towards the sea instead of towards the land (Quart. Journ. Geol. Soc. vol. xxxiii. p. 236). This subject is again referred to in the text.

† It may be proper to notice here that the structure above described proves that Dr. Hicks's estimate of the visible thickness of his "Peibidian" group is greatly exaggerated. He makes the thickness at least 8000 feet (Quart. Journ. Geol. Soc. vol. xxxiv. p. 159). Were the beds absolutely vertical all the way, they could not be more than 4000 feet; for they extend across a belt which, to

In the second place, Dr. Hicks has stated more than once that the Cambrian conglomerates are largely made up of the underlying "Pre-Cambrian" rocks\*. As the result of a most careful examination of the conglomerate belt along both sides of the fold, I feel myself warranted in stating confidently that it contains not a single pebble of the characteristic granite of the St. David's ridge. The actual composition of the conglomerates will be best understood from the percentages taken by Mr. Peach on the west side, and by myself on the east side of the fold.

*Percentage of Stones in the Cambrian Conglomerates.*

West side of Isocline.		East side of Isocline.	
Quartzite (often red).....	70	Quartzite (generally red).....	59
Quartz.....	25	Quartz.....	35
Diabase.....	4	Diabase.....	4
Greywacke.....	1	Greywacke.....	1
		Red Jasper.....	1
	100		100

Thus, of the component pebbles not less than about ninety-five per cent. are of quartzite or quartz. There are certainly no rocks visible in the district whence these pebbles could have been derived. On the other hand, the quartzite resembles the familiar material that forms so conspicuous a feature in the conglomerates and pebblebeds of all geological ages in this country, and the original source of which it is so difficult to fix. The only fragments of undoubtedly local derivation are the few pieces of diabase. These came from some of the lavas in the volcanic series below. But such pebbles would naturally continue to be washed off any volcanic islets still rising above the water, until the last mass of lava or consolidated tuff had disappeared. Their presence lends no support whatever to the idea of unconformability. It is well known that similar

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the S.W. of St. David's, is only three quarters of a mile broad. The visible portion of them cannot be thicker than 2000 feet, but is almost certainly less than that. The bottom, however, is not reached, so that they may attain a considerably greater thickness than can be actually seen.

\* His descriptions of the composition of the conglomerate have varied considerably from year to year. In 1871, in conjunction with Professor Harkness, he described it as "composed chiefly of well-rounded masses of quartz imbedded in a purple matrix," which is a sufficiently accurate diagnosis. In 1877 (Quart. Journ. Geol. Soc. vol. xxxiii. p. 238) he asserted that "the true Cambrian conglomerates undoubtedly contain masses of the underlying rocks in their altered state," the conglomerates themselves being unaltered. In 1878 (Q. J. G. S. vol. xxxiv. p. 162) he stated that they are largely made up of the "Pebidian" rocks. And again, in 1881, "the conglomerates at the base [of the Cambrian rocks] are very largely made up of rolled pebbles and rounded fragments identical with the [Pebidian] rocks below" (Proc. Geol. Assoc. vol. vii. p. 63). As there is a singular uniformity in the character of this conglomerate throughout the district, the variation in these lithological descriptions is remarkable. The first notice of this rock appears to have been that by De la Beche, in the paper already cited, where he speaks of it as a "quartzose conglomerate resembling one of Old Red Sandstone." (Trans. Geol. Soc. ser. 2, vol. ii. p. 9.)



fragments continue to appear in the conformable sedimentary deposits that overlies ancient volcanic rocks. The relation of the conglomerate to the rocks underneath is nowhere better seen than in the excellent exposure of the band on the west side of the diabase crag at Rhosson. The conglomerate there rests almost immediately on the igneous rock, yet 95 per cent. of its pebbles are of quartzite and quartz, only 4 per cent. being diabase, and these derived from some different sheet than that immediately below\*.

As a part of the arguments from included fragments, reference may be made to Dr. Hicks's statement that the volcanic group must have been much in its present lithological condition before a grain of the Cambrian rocks was deposited. The rocks of that group were called "Altered Cambrian" on the Survey Map, doubtless because it was recognized that, whatever might have been their original condition, they had undergone considerable alteration. This altered condition is one of the first features of the rocks to arrest attention. It is not universal, indeed, and is by no means uniform, but in certain bands is so marked that the strata have passed into true silky schists with well-developed foliation. This alteration will be more fully dwelt upon in Part II.

Now, if it could be shown that the metamorphism stops short below the conglomerate, not affecting the beds above that horizon, I admit that the fact might be plausibly used to sustain an attempt to draw a strong line between the conglomerate and the rocks below it. But no such restriction exists. The shales far above the conglomerate have undergone as complete an alteration, and present examples of schists as perfectly foliated as those in the volcanic group beneath. Fine silvery and silky schists are intercalated among grey and purple sandstones that overlie the quartz conglomerate in Porth-Seli, at the south end of Whitesand Bay, and at other localities (see Part II. p. 311).

The facts now stated would be sufficient to disprove the assertion that there is any break in the succession of deposits at the base of the conglomerate. But to complete the argument one further destructive fact remains to be noticed, viz. that the volcanic beds do not cease below the conglomerate, but are interstratified with it and appear above it. In proof of this statement I may refer to the sections on both sides of the fold where this perfect passage can be seen. On the shore of Ramsey Sound, at the headland of Castell, the red shales and sandstones with *Lingulella primava*, which lie not far above the conglomerate, are banded with thin seams of sandy tuff, some of the shales being also full of diffused tuffaceous material, as if from slight discharges of fine volcanic dust during the last stages of eruption in the district.

Again, on the east side of the isocline in the valley of the river Allan, the interesting section shown in fig. 8 may be seen at the upper end of the first field north from the bridge near Lower Mill

\* This locality is referred to by Dr. Hicks (Q. J. G. S. vol. xxxiii. p. 237, 1877) as showing the unconformability of the conglomerate on the rocks below. I cannot conceive how such an assertion can have been made.

Fig. 8. *Section showing the Interstratification of Tuff and Conglomerate above Lower Mill, St. David's.*



The conglomerate, as there exposed, is regularly interstratified with tuff. The beds are vertical. On the left side of the little quarry as we enter it, layers of fine reddish tuff (*a*)\* are succeeded by a band of quartz conglomerate (*b*) of the usual character. Parallel to this conglomerate comes a band, about six inches thick, of fine tuff (*c*), followed by ashy sandstone (*d*), which graduates into conglomerate (*e*). No more complete evidence could be desired of the perfect inosculation of the conglomerate with the volcanic group. On the coast at Nun's Chapel similar evidence presents itself. The conglomerate there contains some thin seams of tuff, and is intercalated between a series of dull green agglomerates and tuffs and some greenish shales and sandstones with layers of tuff.

There is evidence that though volcanic action became dormant (or at least exceedingly feeble) in the interval immediately succeeding that in which the conglomerate was laid down, it reappeared at a later part of the Cambrian period. Thus, about three miles east from St. David's, on the road south from Felin-canot, near Whitchurch, beds of volcanic tuff may be seen overlying Cambrian grits. Again, in a deep valley (Cwm Mawr) between Pointz Castle and Newgale Bridge, on the coast, six miles east from St. David's, a coarse volcanic tuff or agglomerate and ashy sandstone is interstratified in beds which must be high up in the Lower Cambrian formation, certainly far above any of the beds near St. David's. This rock presents petrographical characters somewhat different from those of the tuffs in the volcanic group above described (see Part II.). These intercalations, which were noticed by Mr. Peach and myself as we passed the localities, show that occasional eruptions took place during the deposition of later stages of the Cambrian groups. A more exhaustive search of the whole region would doubtless bring to light other volcanic zones on different horizons, and enable us to connect the volcanic episode of St. David's with that of the Lower Silurian period in North Pembrokeshire.

It follows, from the facts now detailed, that the volcanic group of

\* Red tuff of precisely the same character conformably underlies the conglomerate on the east side of the fold above Caerbwly Mill.

strata named "Pebidian" by Dr. Hicks passes regularly upwards into the fossiliferous Cambrian formations, from which it cannot be dissevered, and with which it must be classed. There is no more reason why a strong line should be drawn between the sedimentary and volcanic groups here than in any other part of the geological record of Great Britain. The intercalation of massive volcanic groups is well known in the Silurian, Old Red Sandstone, Carboniferous, and Permian systems. The Cambrian volcanic group of St. David's is in every respect comparable to one of these, but with an added interest from its high antiquity. It no more deserves to be ranked as a separate formation with a distinctive name than the thick group of tuffs and lavas in the Arenig Series of North Wales, or that in the Old Red Sandstone of Central Scotland. The term "Pebidian," therefore, is unnecessary, and, having been assigned to a group of rocks erroneously believed to be Pre-Cambrian, ought to drop out of geological literature.

### 5. CONCLUSION.

At the beginning of this paper I stated my readiness to concede that the maps of the Geological Survey, originally prepared thirty or forty years ago, may now stand in need of correction, and that in this spirit I went to St. David's, being fully persuaded that, in regard to the map of that district in particular, very serious modifications would be required. As the result of my resurvey, I find that the true meaning of the volcanic group at the bottom of the Cambrian strata there exposed, though partly recognized in the first edition of the Map and Section, had been subsequently lost sight of, these rocks having been erroneously renamed by the Survey "Altered Cambrian" with intrusive sheets of "greenstone." I have freely admitted this to be an important error. But it should be remembered that the error was made nearly thirty years ago. Such, meanwhile, has been the progress of petrography that a mistake of the kind could not have occurred had the map been surveyed during the last fifteen years.

Again, were the area to be resurveyed now, we should not colour as one continuous belt of intrusive rock the long strip of country from the coast near St. David's north-eastward to beyond Llanhowell. We should endeavour as far as possible to represent only those portions of eruptive rock which are actually visible, or unquestionably exist underneath the surface, leaving the intervening spaces on the map to be coloured with the tint used for the general stratified formation of each area. We should prefer to indicate in this way that there are detached dykes and bosses along a certain area of extravasation, rather than to mass the whole as one continuous belt. But this would be, after all, a question of detail or style of mapping. The officers of the Survey were certainly correct in regarding the crystalline rocks, which they named syenite and felstone, as intrusive through the Cambrian strata; and this is the main question in the present discussion.



In concluding this part of my paper, I am bound emphatically to declare that the map of the St. David's district, as surveyed by De la Beche, Ramsay, and Aveline, is in its essential features correct. Dr. Hicks has denied its accuracy, and has even gone so far as to assert that "a very cursory examination" suffices to show its errors. One would have thought that something more than a "very cursory examination" would have been required to upset the mapping laboriously worked out by men who, from long years of training, had acquired an almost unrivalled skill in field-geology. At all events we might fairly have expected that, instead of merely declaring the map to be wrong, Dr. Hicks would take every care to show why, after prolonged consideration, he could not accept the conclusions of his predecessors. Their long years of geological experience, I venture to think, entitled their work, whether right or wrong, to more than a summary dismissal. But the same treatment which Dr. Hicks meted out to them in the St. David's area, he has consistently continued in his subsequent excursions over Wales. Having apparently convinced himself—on what grounds I have endeavoured to show—that the rocks coloured on the Survey Maps as felstone or quartz porphyry must belong to his "Arvonian" group (that is to say, are not intrusive in the Cambrian or Lower Silurian strata, but prominences of Pre-Cambrian age), he has proceeded to apply this conviction to the Geological Survey maps all over Wales. With the most complete disregard of the evidence by which the officers of the Survey were led to regard certain rocks as intrusive, he simply turns the felstones, syenites, &c. into metamorphic and volcanic Pre-Cambrian masses\*. I have deliberately restricted myself in this paper to the discussion of the St. David's district; and I therefore offer no opinion as to the validity of the Pre-Cambrian areas cited by Dr. Hicks in other parts of Wales. But I am sure that geologists generally will support me when I contend that it is not by the "cursory examination" of wide areas that the country can be remapped. This was not the style in which the Survey Maps were constructed; nor is it the style

\* It will be a work of some labour to follow Dr. Hicks in his rapid traverses of Wales, with the view of testing his corrections of the work of his predecessors. Mr. Peach and I had time to visit a few of the areas he has renamed, and always with the same result. Thus, on the coast near Newgale, about eight miles east of St. David's, he describes a mass of Pre-Cambrian beds, chiefly "felstones," "flanked by Cambrian conglomerates containing pebbles identical with the rocks below" (Quart. Journ. Geol. Soc. vol. xxxiv. p. 160). All that we could find was an eruptive rock penetrating and altering black Cambrian shales. Again, he describes the quartz felsites of Roche Castle as belonging to his "Arvonian" group (Quart. Journ. Geol. Soc. vol. xxxv. p. 286). If bedding exists in this rock, I can see no reason why every eruptive rock should not be regarded as bedded, or why, on the same ground, several unconformable Pre-Cambrian formations might not be made out in any good-sized granite-quarry. It is interesting to remember that the true structure and intrusive character of the Trefgarn (Roche-Castle) rock were shown in 1836, by Murchison (*ante*, p. 263). In the 'Silurian System' (p. 402), he says in reference to it that, "though offering no traces of true bedding, the compact felstone of Trefgarn is divided into rude prisms by two sets of planes or vertical and horizontal joints giving rise to square-topped masses like ruins."



in which they should be corrected. The intrusive character and comparatively late origin of the eruptive rocks were deliberately asserted by my colleagues after prolonged examination. Had this view been erroneous, it ought to have been disproved by a detailed review of the evidence on which it was based. I have gone fully into the assertions made by Dr. Hicks himself in regard to the area of St. David's, and have proved them to be untenable. If this is the result of the critical examination of his typical Pre-Cambrian district, over which he has spent most time, I can hardly anticipate that his more rapid traverses elsewhere will, when properly tested, be found to have been more successful.

## PART II.

Apart from the controversy as to their position in geological chronology, the rocks of St. David's present features of interest and importance not only in the palæozoic history of Britain, but in regard to general theoretical questions. They include, for example, perhaps the oldest group of lavas and tuffs the relative date of which is known. They have been subjected to a process of metamorphism which has affected only certain beds or kinds of rock. They have been penetrated by masses of granite and quartz porphyry, round which another kind of metamorphism has been manifested. At a later period they have been injected with diabase dykes, which are specially abundant in the central boss of granite. Evidently, therefore, they offer much material for study, and especially in regard to the two great geological problems of vulcanism and metamorphism. Though my original design included no more than the examination necessary to satisfy me regarding the disputed questions of the geological age and structure of the St. David's district, it naturally led to many observations of more than merely local interest. As contributions towards a more exhaustive memoir, it may be useful to collect these observations made in the field with my colleague Mr. Peach, and subsequently extended with Mr. Topley. I shall embody with them the conclusions to which subsequent reflection on the subject has led me. One of the most laborious parts of the research has been the microscopic investigation of the rocks collected by us at St. David's. I have studied upwards of one hundred slices of these rocks prepared for the microscope, and have had a large additional number cut from rocks of other regions for the purpose of comparison\*. The results of the study are included in the following pages. It is gratifying to be able to state at the outset that, in so far as investigations among the rocks of St. David's have been published, I can confirm generally the descriptions given of the microscopic structure of these rocks by Professors Bonney and Judd, Mr. Davies and Mr. Tawney. But of the larger number of the rocks no account, as far as I am aware, has yet been given. I am also glad to record that the examination of the microscopic structure of the rocks af-

\* These slices were prepared, in the petrological laboratories of the Geological Survey in London and Edinburgh, by A. Macconochie, R. Lunn, and J. Rhodes.

fords the most complete confirmation of the results obtained by us in our observations in the field.

### 1. ORDER OF SUCCESSION OF THE ROCKS.

The extent of the coast-sections, and the repetition of the strata on two sides of an axis of plication, combine to furnish the most satisfactory data for compiling a vertical table of the rocks. But the base of the whole series is not seen. As the line of fold seems to be dying out towards the south-west, it probably for a time brings up progressively lower beds as it is traced inland in the opposite direction, until it flattens out and disappears. The oldest rocks visible to the west and south-west of St. David's belong to the interesting volcanic group referred to in preceding pages. From these a continuous passage can be traced upwards into the purple, grey, and green sandstones and shales from which Dr. Hicks has obtained so abundant a Lower Cambrian fauna. The following groups of strata, from their easily recognizable lithological characters, may be taken as a convenient series for enabling the observer to trace out the general geological structure of the district.

#### *Groups of Lower Cambrian (Harlech) strata at St. David's, in descending order.*

4. Purple and greenish grits, sandstones, and shales.
3. Green and red shales and sandstones, tuffaceous in parts.
2. Quartz conglomerate.
1. Volcanic group (tuffs, schists, lavas, &c.).

#### 1. *Volcanic Group.*

The rocks comprised in this group present so many points of interest that they deserve, and would well reward, a much more detailed study than I have had an opportunity of giving to them. They are the oldest visible portions of the Cambrian system in the St. David's district. They consist almost wholly of volcanic materials, consolidated tuffs and breccias with contemporaneously erupted and subsequently intruded massive rocks. They are exposed in so many sections, and so continuously, both along the shore-cliffs and inland, that their succession and structure could be worked out with little difficulty. If not the oldest group of truly volcanic masses in Western Europe, they (and their equivalents in other parts of Wales) are, as I have said, at least the oldest of which the precise stratigraphical place in the geological record is known. They thus furnish important evidence to the student of the history of volcanic action.

In my examination of these rocks in the field, I was especially struck by their general resemblance to volcanic masses of later Palæozoic date. Many of the lavas and tuffs are in outward characters quite undistinguishable from those of the Lower Old Red Sandstone and Carboniferous systems of Central Scotland. So many points

of detail may be observed to be common to the rocks of the two areas as to indicate that volcanic phenomena must have recurred under much the same conditions throughout Palæozoic time in the British area.

The visible thickness of the volcanic group in the St. David's district appears to be about eighteen hundred feet; but as its base is not brought up to the surface, the total amount may be greater. A continuous section of the rocks is exposed on the sea-cliff between Ogfeydd-duon on Ramsey Sound and the east side of Porth-lisky. This section repeats the members of the group on each side of the isocline, the axis of which must cut the coast-line somewhere between Pen-maen-melyn and Pen-y-foel. I had not time to attempt a detailed examination of the successive members of the group as exhibited in this section; but the main subdivisions appeared to me to be as follows, in descending order:—

4. Fine tuffs and silky schists (occasional breccias and agglomerates), seen at Porth-lisky and Nun's Chapel on the east side, and at Ogfeydd-duon on the west side of the fold. At the latter locality only the upper beds are well exposed.

3. Diabase sheets with intruded quartz porphyry and hardened tuffs, Pen-maen-melyn, Pen-y-foel. The lavas are considerably thicker on the west side.

2. Compact green granular tuff. Inland from old copper-mine at Pen-maen-melyn, and near Pen-y-foel.

1. Thick purplish-red green-flecked tuff, with abundant small lapilli of felsite. This conspicuous rock, in many successive and somewhat variable beds, extends nearly the whole way between the headland at Pen-maen-melyn and Pen-y-foel. It dips at high angles towards the N.W., and shows intercalated shaly bands. It must occupy the centre of the fold; so that the south-eastern dips are inverted ones, and the rocks on that side are a repetition of what is seen on the north-western side of the axis.

From this merely tentative stratigraphical arrangement it is evident how large a proportion of the whole mass of the volcanic group consists of tuffs.

*Tuffs.*—These predominant members of the group present many varieties of colour, from dark purple, through tints of brick-red and lilac, to pale pink, yellow, and creamy white, but not unfrequently assume various shades of dull green. They vary likewise in texture from somewhat coarse breccias or agglomerates, through many gradations, into fine silky schists in which the tuffaceous character is almost lost. Generally they are distinctly granular, presenting to the naked eye abundant angular and subangular lapilli, among which broken crystals of a white, somewhat kaolinized, felspar and fragments of fine-grained felsite are often conspicuous. Examination on the ground suggested that the greater part of the tuffs has been derived from the explosion of basic rocks similar in character to the diabases now found associated with them. This appeared to me to be particularly the case with the purple, red, and dark-green varieties, which constitute so large a proportion of the whole. On the other hand,

I was inclined to regard the paler varieties, both in the form of fine tuffs and of breccias, as having probably resulted mainly from the destruction of more siliceous lavas, probably of fine-grained felsites or other acid rocks. These inferences in the field have now been confirmed by chemical analysis and microscopic examination.

That many of the tuffs are due to the destruction of diabase lavas may be surmised from their close general external resemblance to these rocks, and from the way in which they are associated with the contemporaneous sheets of diabase. Some of the dull dark-purple tuffs below the crag of Rhosson, and again to the north of Clegyr Foig, might almost at first sight be mistaken for truly eruptive rocks. Typical specimens taken from different parts of the district were analyzed for me by my colleague, Mr. J. S. Grant Wilson, in the laboratory of the Geological Survey, Edinburgh, and by my friend M. Renard, of the Royal Museum, Brussels, with the following results.

*Analysis of Basic Tuff's from the St. David's District.*

I. Purplish-red shaly tuff from below the olivine-diabase crag, Rhosson. (Analyzed by Mr. Wilson.)

II. Dull purple and green tuff from the lowest group of tuffs between Pen-maen-melyn and Pen-y-foel. (Analyzed by Mr. Wilson.)

III. Greenish, shaly, finely granular tuff from the road-side, north of Board Schools, St. David's. (Analyzed by M. Renard.) This specimen was chosen as one of the intermediate varieties between the basic and acid types; and the position thus assigned to it is confirmed by the analysis.

	I.	II.	III.
Silica .....	51.25	48.11	61.54
Alumina .....	20.41	13.30	16.30
Ferric oxide .....	3.02	3.70	4.40
Ferrous oxide .....	3.91	8.10	3.66
Manganous oxide .....	0.21	1.43	0.32
Lime .....	4.53	8.48	3.08
Magnesia .....	7.22	9.51	2.99
Potash .....	2.93	1.57	1.62
Soda .....	1.82	1.96	2.81
Loss on ignition and water .....	5.02	4.21	2.99
	100.32	100.37	99.71
Specific gravity.....	2.84	2.92	

Comparing the composition of Nos. I. and II. of these analyses with those of the diabases given on p. 303, we readily perceive how the tuffs might have been derived from lavas like those of Rhosson and Clegyr Foig. The differences between them are not greater than might be expected, if such were the source of the tuffs. There would be a partial decomposition of the volcanic dust and lapilli by the water into which they fell; and there might also be an intermingling with the ordinary non-volcanic sediment that happened to be in course of transit and deposit in the locality at the time of the



eruption. No. III. shows a considerably larger ratio of silica, as was inferred on the ground from its macroscopic characters. It has probably resulted from the admixture of a proportion of felsite detritus with the predominant more basic materials; and it may also have undergone some amount of decomposition before being covered up and compressed into stone.

The occurrence of such basic tuffs in rocks of so high an antiquity is a fact of great interest in the study of the history of volcanic action. But it is further deserving of attention that in the midst of these tuffs there are others of a thoroughly acid character. That felsitic lavas were present in the eruptive vents of the period is shown by the scattered felsitic lapilli in some of the dark-red basic tuffs, and by their abundance in the paler varieties. Even to the naked eye some of the green, white, and yellowish tuffs are obviously composed in large measure of felsitic detritus. I have been favoured by M. Renard and Mr. Wilson with the following analyses of typical specimens.

*Analyses of Felsitic Tuffs from the St. David's District.*

IV. Greenish felsitic breccia, Clegyr Hill (Mr. Wilson). This rock is composed of angular fragments of various felsites imbedded in a greenish base.

V. Grey granular felsitic tuff: the last bed visible, north of the bridge, over the Allan river, north from the Schools, St. David's (Mr. Wilson).

VI. Pale pinkish-white, finely schistose tuff, a characteristic sample of the "Porth-lisky schists" (M. Renard).

	IV.	V.	VI.
Silica .....	80.59	73.42	72.63
Alumina.....	11.29	12.09	16.23
Ferric oxide .....	0.28	0.91	2.70
Ferrous oxide .....	1.41	3.13	0.48
Manganous oxide.....	trace.	0.25	...
Lime .....	0.52	2.94	0.18
Magnesia .....	0.95	1.12	1.36
Potash .....	2.98	1.67	3.35
Soda .....	0.72	3.88	0.15
Loss on ignition and water.....	1.96	1.28	3.04
	100.70	100.69	100.12
Specific gravity.....	2.55	2.74	...

I have had a series of thin slices made from characteristic specimens of the tuffs, taken from all parts of the group. It is one of the most interesting series of volcanic rocks I have ever had an opportunity of studying. Some of the more important details may here be given.

Many varieties of texture can be traced, from large-grained breccias like that of Clegyr Hill to fine schistose mudstones or sericitic schists like those of Porth-lisky. One of the most remarkable tuffs

is that already referred to (p. 295) as No. 2 in the series of the volcanic group. A specimen, taken from near Pen-y-foel, is externally dirty-green, compact, and tolerably homogeneous, but presenting distinct evidence of its clastic character (Plate IX. fig. 1). Under the microscope it is found to be composed mainly of lapilli of a rock somewhat different from any other which I have met with either in the tuffs or among the interbedded or intrusive sheets. This rock is marked by the abundance and freshness of its plagioclase (an unusual feature in the volcanic group of St. David's); by the large, well-defined crystals (one of which measured 0.022 inch by 0.0125 inch) of augite; by large crystals replaced by viridite, but having the external form of olivine; by the absence or scantiness of any base or ground-mass; and, in many of the lapilli, by the abundance of spherical cells, either empty or filled up as amygdules with decomposition-products. These spherical vapour-vesicles, so characteristic of the lapilli in many Palæozoic volcanic vents, were found in one fragment, where they were particularly abundant, to range from a minimum of 0.0008 inch to a maximum of 0.0033 inch, with a mean of about 0.0018 (Plate IX. fig. 2). The rock from which these lapilli have been derived comes nearest to one of the diabases from the same part of the district (which will afterwards be referred to), but shows a closer approach to the basalt rocks.

Another interesting tuff is that of which the analysis (No. II.) has already been given. It occurs not far from the horizon of the rock just described. Under a low power it is seen to be composed mainly of fragments of diabase like the rocks of Rhosson and Clegyr Foig. These fragments are subangular, or irregular in shape, and vary considerably in size. They are sometimes finely cellular—the cavities, as in the rock just described, being spherical. The plagioclase crystals in the diabase lapilli are everywhere conspicuous; so also is the augite, which occurs in larger forms than in the rock of Rhosson or Clegyr Foig. Next in abundance to these basic fragments are rounded or subangular pieces of felsite. These weather out in conspicuous grey rough projections on the exposed face of the rock; under the microscope they are seen to consist of fine granular felsite, which shows a ground-mass remaining dark between crossed nicols, but with luminous points and filaments, and an occasional spherulite giving the usual cross in polarized light. Lapilli of an older tuff may here and there be detected. A few angular and subangular grains of quartz are scattered through the rock. The lapilli appear to be bound together by a finely granular dirty-green substance. The presence of the quartz grains and of the felsite lapilli must raise the proportion of silica, which no doubt, but for these admixtures, would have been a good deal less than 48.11 per cent., the amount determined by Mr. Wilson's analysis.

As a type of the felsitic tuffs, I may refer to the rock already described as No. V. of the foregoing analyses. It is composed mainly of fragments of various felsites, many of which show good fluxion-structure. Large, and usually broken, crystals of orthoclase are dispersed among the other ingredients. Here and there a fragment

of diabase may be detected ; but I could find no trace of pieces of the peculiar micro-crystalline spherulitic quartz porphyries of St. David's. There is but little that could be called matrix cementing the lapilli together. The presence of fragments of diabase may possibly reduce the proportion of silica and increase that of magnesia, as compared with what would otherwise have been present in the rock.

Some of the tuffs appear to have been a kind of volcanic mud. A specimen of this nature collected from the road-side section, north of the Board School, presents a finely granular paste enclosing abundant angular and subangular lapilli of diabase, a smaller proportion of felsite (sometimes displaying perfect fluxion-structure), broken plagioclase crystals, and a greenish micaceous mineral which has been subsequently developed out of the matrix between the lapilli.

Though they lie above the main volcanic group, I may refer here to the thin bands of tuff at Castell, of which, from their interest in relation to the true Cambrian age of the volcanic group, I have had a number of slices made for microscopic investigation (Plate IX. fig. 3). They are not quite so fresh as the tuff that occurs in thicker masses ; but their volcanic origin is readily observable. One band appears to be made up of the débris of some basic rock like the diabase of the district, through which detached plagioclase crystals are scattered. The lapilli are subangular ; and around their border a granular deposit of hæmatite has taken place, giving a red colour to the rock. Another band presents small angular lapilli, almost entirely composed of a substance which to the naked eye, or with a lens, is dull, white, and clay-like, easily scratched, and slightly unctuous to the touch. Under the microscope, with a low power, it becomes pale greyish green and transparent, and is seen to consist in large part of altered felspar crystals, partially kaolinized and partially changed into white mica and calcite. These scattered crystals are true volcanic lapilli, and have not been derived from the mechanical waste of any preëxisting volcanic rock. In the tuffs interstratified with the conglomerate, at the quarry above Porth-clais, though much decomposed, crystals of plagioclase can likewise still be traced. These beds are also true tuffs, and not mere detritus due to mechanical degradation.

The general result of this study of the microscopic structure of the tuffs may be briefly summed up as follows :—

1. They are almost wholly composed of fragments of eruptive rocks, sometimes rounded, but usually angular or subangular. In the more granular varieties very little matrix is present ; it consists of fine débris of the same materials. No detached microliths occur, such as are common among modern volcanic ashes ; but there are abundant ejected crystals. In these respects the Cambrian tuffs are quite like those of the other Palæozoic systems. A mingling of grains of quartz-sand may indicate the intermixture of ordinary with volcanic sediment.

2. They may be divided into two groups—one composed mainly of fragments of diabase or other similar basic rocks, the other of



felsite. The former group may have been derived from the explosion of such rocks as the diabase-sheets of the district. The felsitic tuffs have not been observed to contain any fragments of the micro-crystalline quartz porphyries of St. David's. They have been derived from true fine-grained felsites. There are various intermediate varieties, due to the mingling in various proportions of the two kinds of *débris*.

3. They are marked by the presence of some characteristic features of the volcanic vents of later Palæozoic time, and in particular by presenting the following peculiarities:—(a) minutely cellular lapilli with spherical cells; (b) lapilli with well-developed fluxion structure; (c) lapilli consisting of a pale green serpentinous substance resembling altered palagonite; (d) lapilli derived from the destruction of older tuffs; and (e) lapilli consisting of ejected crystals, especially of felspars, sometimes entire, frequently broken.

4. They frequently show that they have undergone metamorphism, by the development of a pale greenish micaceous mineral between the lapilli, the change advancing until the fine tuffs occasionally pass into fine silky hydromica schists. To this metamorphism further reference will be made in the sequel.

I was unable to observe any evidence that the basic and siliceous tuffs characterize two distinct periods of volcanicity. From the foregoing analyses it appears that some of the oldest visible tuffs which are seen between Pen-maen-melyn and Pen-y-foel contain only 48·11 per cent of silica: a specimen from Porth-lisky yielded 72·63 per cent. of that ingredient. Specimens taken even from adjacent beds show great differences in the percentage of silica, as may be seen in the analyses Nos. III. and V.

This alternation of basic and siliceous fragmental materials has its parallel in the neighbouring eruptive rocks, some of which are olivine diabases containing only 45 per cent. of silica, while others are highly siliceous quartz porphyries. But all the siliceous eruptive rocks, so far as I have been able to discover, are intrusive, and belong, I believe, to a much later period than that of the volcanic group; in no single instance did they appear to me to be true superficial lava-flows. On the other hand, the basic eruptive rocks occur both as contemporaneous sheets and as intrusive masses. The presence of both siliceous and basic lavas in the Cambrian volcanic reservoirs, however, is proved by the character of the tuffs. It would appear that while the basic lavas were most abundant during the volcanic period recorded by the rocks of St. David's, furnishing the material for most of the fragmental eruptions, and pouring out at the surface in streams of molten rock, the siliceous lavas did not flow forth at the surface, but were copiously discharged in the form of dust and lapilli.

The rise of both basic and acid lavas at different periods in the same or adjoining vents, so familiar in recent volcanic phenomena, thus appears to have also characterized some of the oldest examples of volcanic action. An interesting parallel may be traced between the succession of events at St. David's and that which has occurred



in the volcanic group of the Lower Old Red Sandstone of the Pentland Hills, near Edinburgh. In the latter area the volcanic accumulations attain a depth of more than 5000 feet, and are composed of successive sheets of basic lavas, with alternations of felsitic tuffs, in which the proportion of silica ranges between 60 and 70 per cent. Intrusive veins of felsite intersect these tuffs and porphyrites; but no case has there been observed of any such rock having been poured out as a superficial lava-stream.

Though the volcanic group of St. David's consists almost wholly of volcanic materials, the tuffs contain evidence that ordinary sedimentation was not entirely interrupted by the volcanic discharges. Thus, in the Allan valley, west from the Cathedral, one of the schistose tuffs is full of well-rounded pebbles of white quartz. Occasional shaly bands indicate the deposit of mud with the tuffs.

Seams of pale silky schist occur among the tuffs, similar in texture and composition to bands that lie on various horizons among the Cambrian sandstones and shales. These may originally have been fine volcanic dust or mud. One of the most prevalent features, indeed, among the finer varieties of tuff is the development in them of a fine foliation, whereby they pass into silky schists, and might be classed with the sericite schists of metamorphic districts. This structure will be described in connexion with the later changes which the rocks of the district have undergone.

*Uppermost Zone of Schists, Shales, Siliceous Bands (Adinole, Kiesel-schiefer.*—In the first part of this paper (p. 279) reference has been made to a remarkable band of strata lying between the volcanic group and the quartz conglomerate, and serving, from its peculiar lithological characters, as a convenient, because easily recognizable, horizon for tracing out the structure of the district. It must be considered as part of the volcanic group, but with an admixture of non-volcanic sedimentary material. It probably indicates the resumption of ordinary sedimentation as volcanic action became gradually feebler.

The component rocks of this zone are fine tuffs, passing, on the one hand, into fine grey shales, and, on the other, into pale schists, but occasionally including bands of coarser tuff, seams of quartzose sandstone or quartzite, and abundant siliceous aggregations.

The schists are exceedingly fine, silvery, hydromica schists, unctuous to the touch. They pass into fine tuffs and into shale; indeed, they must be regarded as a metamorphosed condition of beds that were originally fine tuffs and shales. They vary very much in their power of resisting disintegration, some portions standing their ground well, as in Ramsey Sound, other parts decaying into a soft, white, or yellow clay, as at Porth-lisky.

One of the most conspicuous features of this zone in the St. David's district is the remarkable abundance of its siliceous aggregations. The material of which these consist varies considerably in colour, texture, structure, and composition. In some instances it occurs in bands having a finely granular texture like beds of altered shale; in others the bands are flinty and translucent. It

may be observed also in detached nodules and in strings and veins crossing the bedding of the strata.

To this substance various names might be given, according to the varying circumstances under which it is found. Much of it might be classed with the "siliceous schist" or "Kieselschiefer" of the older petrographers; some of it assumes the characters of the "Horn-schiefer" found in areas of contact-metamorphism. In other places it resembles the eurites or hälleflintas of regional metamorphic areas. Occasionally it becomes almost sufficiently flinty and translucent to deserve the name of chert. From the analysis kindly made of it for me by M. Renard, some portions answer exactly to Beudant's "adinole"—a term which has been revived by German petrographers. It is obviously not a definite chemical compound, nor has it any uniform microscopic structure. It includes the "hälleflintas" of Dr. Hicks.

To what extent the silica of these aggregations is due to original deposition, is a problem to which I shall recur in the sequel. From the fact that the cherty material ramifies in veins across the bedding, its introduction must certainly, to some extent at least, be later than the deposition of the shales and tuffs which it traverses. I shall be able to show, indeed, when describing it more fully in a later part of this paper, that its appearance has certainly been, in some cases, later than that of the quartz porphyries, and that its production has been connected with the general process of extrusion of the highly silicated rocks of the granite tract.

*Lavas of the Volcanic Group.*—There remain for notice here the sheets of eruptive rocks that occur among the tuffs. Excluding the granites and porphyries (to which a special section of this paper will be devoted), two kinds of eruptive rocks are associated with the volcanic zone. One of these is certainly intrusive and of late date, viz. dykes and veins of diabase, which will be described in later pages. The other kind occurs in long parallel sheets, some of which, if not all, are true contemporaneous lava-streams, erupted at intervals during the accumulation of the volcanic group. They form prominent crags to the west of St. David's, such as Clegyr Foig, Rhosson, and the rocky ground rising from the eastern shores of Ramsey Sound. Their dip and strike coincide with those of the tuffs above and below them. It is possible that some of these sheets may be intrusive along the bedding of the tuffs; and in one or two cases I observed indications of what, on further and more careful exploration, may prove to be disruption across the bedding.

But it is the interbedded sheets that possess the chief interest as superficial lava-streams of such venerable antiquity. They present many of the ordinary features of true lava-flows. In particular a slaggy structure may be detected at the bottom of a sheet, the vesicles being here and there lengthened in the direction of flow. Some of the sheets are in part amygdaloidal. The alternation of these sheets with tuffs, evidently derived from lavas of similar character, is another argument in favour of their contemporaneous date. One of the best localities for studying these features lies

between Clegyr Foig and the coast, west of Rhosson, where the following section may be observed.

The eruptive rocks thicken towards the south-west, as if the main vents had lain in that direction. There are doubtless intrusive as well as contemporaneously interbedded masses in the rough ground between Pen-maen-melyn and Treginnis. To separate these out would be a most interesting and beautiful piece of mapping for any competent geologist in possession of a good map on a sufficiently large scale.

The interbedded lavas, so far as I have had an opportunity of studying them, appear to present remarkable uniformity of petrographical characters. Macroscopically they are dull, fine-grained to compact, sparingly porphyritic, ranging in colour from an epidote-green to dull blackish-green and dark chocolate-brown. Some of them are finely porphyritic from the presence of small glistening surfaces which present the colour and metallic lustre of hæmatite and yield its characteristic streak. Obviously basic rocks, they present, as I have said, a close resemblance to many of the porphyrites of the Lower Old Red Sandstone and Carboniferous districts of Scotland. So marked is this likeness that Mr. Peach and I at once classed them as porphyrites, so far as their characters could be judged of in the field. Subsequent microscopic study of them, while showing that the resemblance descends even to minute details, has brought to light some features that are seldom seen in the Scottish examples, and has led me to class these rocks with the diabases.

Two of the most conspicuous rocks of this class in the district, those of Rhosson and Clegyr Foig, have been analyzed by Mr. Wilson, with the following results.

*Analyses of Diabases from St. David's by Mr. J. S. Grant Wilson.*

	Rhosson.	Clegyr Foig.
Silica .....	45.92	45.38
Alumina .....	18.16	16.62
Ferrie oxide .....	1.18	4.06
Ferrous oxide .....	9.27	8.63
Manganous oxide .....	0.19	0.14
Lime .....	7.19	8.19
Magnesia .....	10.07	9.41
Potash .....	1.78	0.71
Soda .....	2.12	2.20
Loss on ignition and water ..	4.22	4.34
Insoluble residue .....	0.04	0.08
	<hr/>	<hr/>
	100.14	99.76
Specific gravity .....	2.96	2.99

The strikingly basic composition of the rocks is well brought out by these analyses. It may be difficult at first to believe that the specimens were not taken from some modern basalts. That the lavas



of the Cambrian period possessed such a composition, however, is put beyond question by the analyses of the basic tuffs already given ; so that it is not necessary to endeavour to discover a late and intrusive origin for the sheets of Rhosson and Clegyr Foig.

I have examined under the microscope thin slices taken from the rock at both the localities just named, also from the crag south of Castell, and from the cliffs at the southern end of the promontory between Ramsey Sound and Pen-y-foel (Plate IX. fig. 4). In all of these the general composition is alike. There is a variable quantity of a base, which under a  $\frac{1}{5}$  objective is resolved into ill-defined coalescent globulites and fibre-like bodies, which remain dark when rotated between crossed nicols. In some varieties, as in part of Rhosson Crag, the base is nearly lost in the crowd of crystalline constituents ; in others, as in the crag south of Castell, it forms a large part of the whole mass, and may be seen in distinct spaces free from any crystalline particles. Through this base are diffused, in vast numbers, irregularly shaped grains of augite, seldom showing crystalline faces with measurable interfacial angles. These grains, or granules, may perhaps average about 0.003 inch in diameter. Plagioclase is generally hardly to be recognized, though here and there a crystal with characteristic twinning may be detected in the base. Magnetite occurs abundantly—its minute octahedra, with their peculiar colour and lustre, being apparent with reflected light on the fresher specimens, though apt to be lost as diffused ferruginous blotches in the more decomposed varieties. But perhaps the most remarkable ingredient is olivine. I have referred to the red hæmatitic crystals which, even to the naked eye, are visible, dispersed through the ground-mass of these rocks. With a lens these may be observed to be orthorhombic in form and to be evidently pseudomorphs after some mineral which has been converted chiefly into hæmatite. I have often noticed red pseudomorphs (ferrite, as they have been called) in Carboniferous and Old Red Sandstone porphyrites, where in some cases they appear to be after hornblende, and in others after augite, but occasionally are suggestive of olivine, though with no trace of the original substance of that mineral. In the lava associated with the tuffs at the south end of the promontory between Ramsey Sound and Pen-y-foel, however, I find some large, well-developed pseudomorphs, which are certainly after olivine. They have the characteristic contour of that mineral and its peculiar transverse curved and irregular fractures. The average length of these pseudomorphs was found, from the measurement of six examples, to be 0.023 inch, the largest being 0.034, and the smallest 0.014. Seen by transmitted light they present a structureless pale-green material nearly inert in polarized light, round the borders and across fissures in which an opaque substance has been developed, as serpentine has been in the familiar alteration of olivine. The pale-green matter may be the result of a first alteration, subsequently replaced along the borders and across the fissures by the dark substance. With reflected light the latter is found to be bright brick-red. It is evidently chiefly hæmatite. Every stage may be traced,



from orthorhombic forms with the incipient development of transverse fissures filled with hæmatite, to others of distorted shapes in which the ferruginous matter occupies the whole or nearly the whole of the mould of the original crystal.

The rocks now described differ from the Palæozoic porphyrites with which I am acquainted in the less abundance of their microscopic base, in the comparatively inconspicuous development of feldspars, and the absence of large porphyritic feldspars, in the extraordinary prominence of the augite, and in the presence of olivine. In composition and structure they are essentially forms of olivine diabase.

I cannot pretend at present to offer more than a mere outline-sketch of the petrography of the Cambrian volcanic group of St. David's; but from the data here brought forward it will, I think, be apparent that the rocks of that group possess exceptional interest from the extraordinary combination of modern types of structure with so remote an antiquity.

## 2. *The Quartz Conglomerate.*

The lithological characters of this band and its stratigraphical relations to the beds beneath it have been sufficiently described in Part I. (p. 286). It is essentially a mass of rolled pebbles of quartzite and quartz, embedded in a reddish ferruginous and quartzose matrix. The pebbles vary up to occasional blocks as large as a man's head or larger; but their average size is probably less than that of a walnut. The conglomerate band continues as a persistent and easily recognizable horizon through the St. David's district, but presents noticeable variations in thickness and in coarseness of materials. The pebbly beds are lenticular, rapidly wedging out and passing into fine grit and sandstone. In some places the total thickness of the band dwindles down to possibly not more than two or three feet; in others, as on the south-east of St. David's, it swells out to more than one hundred feet. I have alluded in the first part of this paper to the perfect conformability of the conglomerate with the top of the volcanic group, and to the intercalation of bands of tuff in it (fig. 8, p. 290). These facts prove that no abrupt break can be traced between the volcanic group and the conglomerate. I have also referred to the presence of occasional seams of rolled quartz pebbles in the tuffs, as indicating that the conditions of deposit to which the conglomerate was due had begun to appear even during the volcanic period. It is obvious, however, that the intercalation of the marked band of quartz conglomerate points to an important change in the sedimentation of the time. It suggests some interesting questions of general interest, to which reference may here be made.

There can be no doubt that conglomerates frequently mark the natural base of a series of sedimentary deposits. They do so more especially where they are formed of materials that have had an obviously local origin, and where they rest unconformably on the

rocks below, from the waste of which they may have been mainly derived. In such cases they must be regarded as littoral deposits; and in this respect they possess importance from the light they throw on former geographical conditions. But it is equally certain that pebble-beds and conglomerates have again and again been intercalated, without discordance of any kind, in the midst of a continuous and strictly conformable series of sandy and even of muddy and calcareous deposits, often marked throughout by a community of fossil contents. In such positions they may possess local value as stratigraphical horizons, but they evidently cannot be regarded as marking important geological breaks in the succession either of formations or of organic remains. Under these conditions they present certain common features that recur over and over again throughout the stratified formations of the earth's crust. Unlike the basal conglomerates just referred to, they are composed of well waterworn pebbles, for the most part comparatively small in size, derived from some distant and, in many cases, unknown source, and consisting usually of quartz, quartzite, or other exceptionally durable rocks.

These features are characteristically displayed in the conglomerate of St. David's, which is the earliest of the British examples yet known. A long list of similar intercalated pebbly bands might be drawn up from all the later geological systems down to the shingle beds of the present sea-bottom; but a few examples may be cited in illustration\*.

The Lower Silurian rocks of Anglesey contain bands of conglomerate made up of pebbles of quartzite, sometimes from 6 to 8 inches in diameter, and mostly well rounded†. Conglomerates of quartz and black slate occur high up in the Skiddaw Slates‡. Conglomerate bands of white quartzite and vein-quartz occur in the "Plynlimmon Group" of Central Wales§.

In the Old Red Sandstone, bands of quartz conglomerate appear on many different horizons. One of the most striking examples is the coarse and thick mass that comes in conformably above the fine Ludlow shales and mudstones of Lanark and Ayrshire.

In the Carboniferous system lines of quartz conglomerate occur on many platforms. The Carboniferous Limestone contains excellent examples in the north of England, hundreds of feet above the base of the formation. The Millstone Grit affords a familiar illustration; and occasional instances occur in the Coal-measures.

The Bunter pebble-beds, composed of white and liver-coloured quartz, are notable examples of the occurrence of conformable conglomerates in a continuous series of sediments, with occasional

\* I am indebted to Mr. W. Topley for kindly furnishing me with most of the references in the list given above, which have been supplied from the field-notes of my colleagues in the Survey, Messrs. Bristow, Whitaker, H. B. Woodward, Goodchild, De Rance, Ussher, and Strahan.

† Ramsay, *Geology of North Wales* (Geol. Surv. Mem. vol. iii.), 2nd edit. p. 247.

‡ J. C. Ward, *Geol. Mag.* dec. 2, vol. vi. p. 51.

§ W. Keeping, *Quart. Journ. Geol. Soc.* vol. xxxvii. p. 156.

illustrations of contemporaneous erosion. The Budleigh-Salterton pebble-bed and its continuation through the middle of the Triassic system is another well-known case.

In the Jurassic series of Yorkshire examples of intercalated conglomerates have been noted\*.

The conglomerates of the Weald generally occur near the top of the sandstone beds and are succeeded by shales†. The conglomerates of Faringdon and Godalming &c. exhibit similar phenomena in the Neocomian series.

Of the Tertiary illustrations I need refer only to the pebble-beds of the London basin‡, and the thick shingle-accumulations of the Marine Series of Bournemouth§.

Every geologist who has studied the subject in the field must be familiar with the way in which the same far-transported pebbles have been used over and over again in successive formations. In some cases, as, for example, in the later conglomerates of the Isle of Arran, it is possible to distinguish the freshly derived fragments from those that had already done duty in an earlier conglomerate.

It is evident, then, that the intercalation of a conglomerate band in the midst of a continuous series of sediments has been of frequent occurrence in the geological past. Sometimes no change has taken place in the general character of the sedimentation after the conglomerate was deposited; in other cases the sediment laid down above the conglomerate differs in composition or texture, or in both, from that which lies below. We may infer from these facts that the occurrence of a pebbly zone in a conformable series of strata, need have no more geological significance than the shifting shingle banks on the bed of the English Channel at the present day. Undoubtedly such a band of conglomerate points to a change in the system of currents by which sediment was transported, the change sometimes giving way to the former conditions, sometimes introducing new ones; but it furnishes no sufficient ground for an important stratigraphical boundary line.

### 3. *Zone of Green and Red Shales, Sandstones and fine Tuffs.*

This zone is chiefly important because it offers well-marked lithological characters, capable of being employed in working out the stratigraphical succession and general structure of the district. In mapping the ground, indeed, Mr. Peach and I found it convenient to distinguish two bands in this zone, viz. a lower set of green, and an upper set of red beds. But the line of demarcation is not always sharply defined between them, though they can be readily observed in their respective positions on both sides of the axis. They are

\* C. Fox Strangways and G. Barrow, Mem. Geol. Survey, 'Geology of Whitby and Scarborough,' p. 38.

† W. Topley, Mem. Geol. Survey, 'Geology of the Weald,' pp. 56, 59, 64, &c.

‡ W. Whitaker, Mem. Geol. Survey, vol. iv. 'Geology of the London Basin,' pp. 207, 222-224, 233.

§ J. S. Gardner, Quart. Journ. Geol. Soc. vol. xxxv. p. 215



specially well developed and marked off from each other on the coast-line south of St. David's. They may also be studied at Castell, on Ramsey Sound.

One of the most interesting lithological features in these strata is the presence in them of diffused volcanic dust and of layers of fine tuff. Some of the red shales are full of this material, which here and there is gathered into the thin seams or ribs of which the microscopic characters have already been described. This diffused volcanic detritus marks, no doubt, the enfeebled discharges of fine dust towards the close of the volcanic episode in the Lower Cambrian period at St. David's. It would be difficult to find an instance of a more perfect transition from a series of thoroughly volcanic masses into a series of ordinary mechanical sediments.

It is further to be noted that in this zone, as discovered by Dr. Hicks, well-preserved specimens of *Lingulella primæva* occur\*. There can, therefore, be no doubt as to the place of the strata in the geological record. The red sandstones and shales pass up insensibly into a thick overlying mass of fossiliferous purple and green sandstone, assigned by Dr. Hicks to the Harlech Group. It is not needful here to pursue further the upward stratigraphical succession.

## 2. GEOLOGICAL STRUCTURE OF THE DISTRICT.

The existence of an anticlinal axis in the Cambrian beds at St. David's is indicated upon the Geological Survey Map, which does not, however, distinguish the different zones of rock in such a way as to show the line of axis, or to afford data for measuring the thickness of the beds. As I have already pointed out, there is not only a great arch of the strata here, but the south-eastern half of the arch has been inverted. As the determination of this isoclinal fold is a point of fundamental importance in the structure of the district, some further details regarding it may here be given (see figs. 1 & 2, p. 268).

On the west side of the district the succession of beds can be followed from the headland of Point St. John without interruption, along the shores of Ramsey Sound, for about a mile south-eastward. The strata of sandstone and shale, traversed here and there by eruptive rocks, dip in a general north-westerly direction. Hence there is a steadily descending section until near Castell, where the shore trends toward the south-west, and coincides with the general direction of the strike of the beds. Whether we follow the coast-line round into Porth-lisky, or strike inland across the promontory to that bay, we encounter a thick series of tuffs (with bands of diabase and occasional intrusive elvans or veins of quartz porphyry) presenting the same general dip towards W.N.W. or N.W. The angles of inclination are generally high, though here and there they fall as low as 40° or even less.

No one visiting this section for the first time would suspect that one half of it is only a repetition of the other half; but when the

\* Quart. Journ. Geol. Soc. vol. xxxi. p. 168.



same zones can be recognized on each side of the promontory the existence and nature of the fold are made apparent. We need not look, indeed, for more than a general agreement in the repetition of the volcanic part of the Section. Volcanic accumulations are so characteristically inconstant that the series on each side of the fold might quite well be entirely different. The coarse tufts and breccias were doubtless thrown up in heaps round the vents from which they were discharged. The lavas must have formed submarine banks or reefs of but limited extent. Not only, therefore, might we expect that the succession of volcanic masses on one side of the axis would differ from that on the other, but there might very well be local overlaps of the conglomerate upon the irregularities of the volcanic masses. West of Treginnis-uchaf, where the prolongation of the Rhosson diabase reaches the shore, there seems to be an instance of this kind, the conglomerate ending against the diabase bank on one side but reappearing on the other. Such a structure, however, is obviously quite different from an unconformability. Even at the locality just referred to the conglomerate is succeeded by fine volcanic tuff, showing that, though the conditions of sedimentation had considerably changed, volcanic action still continued.

Even in the volcanic group, however, some leading features are repeated on either side of the fold. The Pen-maen-melyn lavas reappear, though in diminished proportion, on the east side near Pen-y-foel. The diabase sheet at Rhosson may be the same as that of Clegyr Foig. The Porth-lisky schists are partially exposed on the coast of Ramsey Sound at Ogfeydd-duon; and the conglomerate with its overlying groups is easily traced on either side of the fold\*.

Various eruptive masses have been protruded through the stratified rocks. It is possible, as I have already suggested, that some of the diabase sheets in the volcanic group may be intrusive; but if so, they must still, no doubt, be classed as belonging to the volcanic period, like the intrusive rocks associated with the contemporaneous volcanic series in the Carboniferous system of Central Scotland.

Of much later date are the granite and quartz-porphyrries. For reasons to be afterwards given I class these two groups of highly silicated rocks together. A reference to the Map (Pl. VIII. p. 268) will show that the granite has risen through the eastern limb of the isocline, considerably disturbing the symmetry of the structure. In a general sense the longer axis of the granite mass corresponds with the domi-

\* The repetition of the same petrographical character has been admitted by Dr. Hicks himself, as may be seen in the sections published by him in his paper of May 1878 (*Quart. Journ. Geol. Soc.* vol. xxxiv. p. 166). In Nos. 1 and 2 of these sections subdivisions 1, 2, 3, 4, 5 and 6 are described in nearly the same words as subdivisions 8, 10 and 11. It is interesting to find that he makes the Cambrian conglomerate to be underlain by the same succession of beds at Llanhowell and Caerbwly, though those localities are upwards of three miles apart. This would hardly be likely to occur were there an unconformability between the conglomerate and the rocks below it. [At the reading of this paper Mr. Peach exhibited Dr. Hicks's section, coloured in accordance with what we believe to be the true structure of the ground; and he showed how entirely that section is explicable on the idea of an inverted anticline.]

nant strike of the stratified rocks without strictly conforming to it. I have shown how the granite cuts into successive zones of the Cambrian series, until it invades the group of greenish sandstones and shales lying above the conglomerate. The most serious disturbance of the regularity of the beds on the south-eastern side of the fold occurs in the Allan valley between Rhoscribed and Porth-clais. There appears to be a minor plication between the two projections of granite, as expressed on fig. 1, p. 238. Beyond this local disturbance the strata can be followed eastward until the reversed dip of the isocline changes to vertical; and the beds rapidly lessen in inclination as group after group of the Lower Cambrian series appears in normal order.

The St. David's area is one of the numerous tracts of Pembroke-shire where eruptive masses have risen in a general north-east and south-west direction parallel with the principal stratified rocks. Round the granite are grouped various quartz porphyries; and similar rocks probably continue to rise in detached bosses or dykes along the same line of extravasation towards the north-east.

From the way in which the granite and porphyries traverse the stratified rocks, it may be confidently inferred that they are of later date than the general plication. At the same time there is evidence of movement subsequent to the intrusion of these rocks; for slicken-surfaces may often be noticed on their joints.

In the first part of this paper I have admitted that minor local displacements may have occurred here and there along the edge of the granite; but they do not in any way affect the general geological structure of the district. That no large or important faults occur is made quite certain by the remarkably clear coast-section, and by the evidence of the transverse valley of the Allan river, in which, in spite of the intrusion of the granite, the normal succession of beds can be distinctly recognized. If, indeed, the granite could be eliminated from the district, the various groups of strata on either side of it would close up into their usual order.

The latest rocks are the dykes of diabase, by which all the others are traversed. These show occasionally a kind of cleavage or fine-jointing, which may perhaps point to renewed lateral pressure after their extrusion.

Cleavage was not observed to characterize the stratified rocks, though we noticed a few feeble examples of it. But the fine foliation already referred to is conspicuous in the volcanic group and on several horizons in the groups overlying the conglomerate. To this structure I shall devote a separate section of the paper.

### 3. THE FOLIATION OF THE DISTRICT.

A fine foliation, arising from the development of micaceous minerals along the planes of stratification, has been extensively developed in the volcanic group, and likewise in the groups of ordinary sedimentary strata overlying the conglomerate. It has affected many of the fine tuffs, the paste of certain coarser tuffs, and some of the

shales. Where it occurs, the rock is usually pale apple-green to pearl-grey, but occasionally of a pinkish tint, with a silky lustre, soapy feel, and finely schistose texture. These characters have been developed here and there along particular lines or in certain bands of rock, the beds above and below exhibiting no appreciable trace of them. A specimen taken from one of the foliated beds might be supposed to have come from the sericite schists, or fine hydro-mica schists of a district in which regional metamorphism has been well and widely developed. Yet the beds immediately above and below are ordinary tuffs, shales, or sandstones.

I have had thin slices prepared from specimens collected from different horizons, to show various stages in the development of this foliation (Pl. IX. figs. 5 & 6). Some of these are from the section on the road-side north from the St. David's Schools; others from the schists at Porth-lisky and from the same group at Ogfeydd-duon on Ramsey Sound. Others, illustrating the alteration of the beds above the conglomerate, were taken from schistose bands among the ordinary strata at Porth-seli; at the Life-boat House, Porth Stinian; and at Porth Cadnaw, a little south from St. John's Point. I can offer, at present, only the general results of a first study of these slides; but the examination has convinced me that the district is one from which a more exhaustive research could not fail to derive much fresh insight into the early stages of regional metamorphism.

The original clastic character of the rocks is still everywhere raceable, but is less distinct among the lower and older portions of the series. This probably arises from the original mineral constitution and state of aggregation of the fine fragmentary materials, rather than from relative age and depth. The base of the schists appears, under the microscope, as a felted aggregate mainly composed of minute scales of a nearly colourless mica. These scales are grouped linearly along the planes of foliation, which coincide in general direction with those of bedding. They wrap round the clastic granules, and are not unfrequently interlaced into short folia. The mineral thus developed in the process of foliation is doubtless one of the hydrous micas, so frequently observable in the metamorphic schists; it may be sericite. Next in abundance to it is an opaque granular substance with no recognizable crystalline form, which has, as it were, been pushed aside by the crystallization of the mica, and is disposed in lenticular and coalescent folia along the general planes of foliation. It is the presence of these sharply defined streaks of black dust which gives so much precision to the line of foliation in many of the slides. Another mineral of secondary or metamorphic origin is bright green, fibrous, and granular, tufted or vermicular. From these characters and its behaviour in polarized light, I have little doubt that it is chlorite. It occurs in oval or eye-like nests, but occasionally is prolonged into folia, and sometimes takes the place of the nearly colourless mica. Its fibres are usually disposed transversely to the longer axis of the aggregates. In one slide (Ogfeydd-duon) abundant crystals of pyrites have been developed along some of the folia; in another (Life-boat House), minute



grains of what appears to be magnetite are dispersed through the base.

Of the elastic fragments still recognizable, quartz is most conspicuous. It presents the usual characters of sand-grains, with lines of fluid inclusions. These grains usually show sharp borders.

Among the schists of the volcanic group there occur small fragments of felsite, with less sharply defined margins, which I cannot doubt were originally volcanic lapilli. I conjecture also that the ovoid aggregates of chlorite may represent the augite and olivine of the more basic fragments. The schists, it will be remembered, are interstratified among tuffs in which felsite and porphyrite lapilli are quite distinct.

The schists intercalated among the sandstones and shales above the conglomerate, present essentially the same structure and the same ingredients as those among the tuffs below. So close, indeed, is the resemblance, that I am inclined to look upon these schists as having been originally fine tuffs. They contain, as might be supposed, a larger proportion of quartz-sand; but their sericitic constituent is well developed.

One further microscopic character may be referred to. A slide taken from a band of fine schist, among the tuffs beyond the bridge over the Allan to the north of the Board Schools, shows an incipient crumpling of the folia (Pl. X. fig. 7). Some of the lines of black dust are bent back upon themselves in the way so familiar in mica schist and gneiss. Instances also occur where a similar crumpling is presented by the sericite and chlorite.

There cannot, I think, be any hesitation in affirming that the foliation of these fine schists has had nothing whatever to do with the protrusion of the granite and quartz porphyries. It is not specially developed near these rocks, and, on the other hand, is admirably exhibited at a distance from them. I am inclined to believe that not only is the foliation independent of the eruptive rocks, but it took place long before their protrusion. It was probably connected with plication, as appears to have been so generally the case in areas where rocks have been subject to this kind of metamorphism. The eruptive rocks themselves show no trace of foliation; but they could hardly have escaped this change had they already been in position when the schistose structure was being superinduced upon the adjoining strata.

What renders the foliation of the St. David's area so interesting is its feeble development, and its singularly sporadic and almost capricious distribution. In many places one cannot always decide whether to regard a given rock as a true foliated schist or simply as a shale. The same part of a group is shaly at one locality and schistose at another. Some strata seem to have been able to resist the change throughout the district; the red shales above the conglomerate, for example, remain true shales, though some of the bands of tuff intercalated in them show faint foliation. Others, again, have been prone to change. This appears to have been particularly the case with some kinds of fine volcanic débris. The microscopic



examination suggests, indeed, that all the schists were originally tuffs. The green and grey shales lying below and above the conglomerate, which include such excellent examples of fine silky schists, were not improbably derived in large measure from fine volcanic sediment.

My second visit to St. David's was especially intended to obtain further data regarding this question. But I am not yet able to throw much light upon it. There can, I think, be no doubt that, in so far as the production of a true foliated structure depended upon the operation of influences entirely outside of the rocks themselves, closely adjacent strata must have been under practically the same conditions. The pressure, tension, and temperature can hardly have sensibly differed in contiguous rocks. If, therefore, all the rocks were subjected to the same processes, any resulting differences in their present aspect and structure must, I should imagine, be due to some original variety in the chemical composition and physical structure of the rocks themselves. Certain layers or particular kinds of fine detritus, more especially some of the finely comminuted volcanic dust, have been specially susceptible of change along the planes of deposit; and sericite, chlorite, pyrites, and magnetite have been developed along those planes, so as to produce a marked foliation.

In the St. David's district we seem to stand in presence of some of the initial stages of that still mysterious process by which wide regions of sedimentary strata have been changed into crystalline schists.

#### 4. THE GRANITE, QUARTZ PORPHYRY, AND ACCOMPANYING METAMORPHISM.

In the first part of this paper sufficient evidence has been adduced to show that at St. David's a central boss of eruptive granite, with associated peripheral dykes, elvans, or amorphous intrusions of quartz porphyry, has been protruded through the Cambrian strata. I purpose now to supplement that evidence by discussing more fully the structure and relations of the eruptive rocks, and the influence they have exerted upon the stratified formations through which they have arisen.

The granite, as has been already shown, lies on the eastern limb of the isocline, where it invades the various rock groups up to the zone of green shales and sandstones that lies some way above the quartz conglomerate. The porphyries are grouped round the central boss of granite, and appear to be intimately connected with it, like the elvans of granite districts. I shall first describe the petrographical characters of these rocks, and then give some account of the metamorphism associated with them.

Of the granite I have had a good series of thin slices prepared from characteristic specimens taken from all parts of the district, and have subjected them to microscopic examination (Plate X. fig. 11). To the descriptions already given by Prof. Bonney, Mr. Davies,

and Mr. Tawney I have but little to add regarding the structure of the mass in its central typical portions. It is a thoroughly crystallized compound, with the distinctive micropegmatite structure of a true granite. The quartz is specially abundant in some places, and always presents the characteristic forms of this mineral in granite. The feldspars are all more or less kaolinized; striated forms may be detected among the more predominant orthoclase; while here and there a little microcline (a species so characteristic of granite) may be observed. In none of my slides have I found any mica; but in all of them there is an abundant bright grass-green mineral, often in tufts and vermicular aggregates. Most of this green constituent appears to be chlorite. Nests of epidote may also be detected, some of it possibly replacing original mica. The presence of chlorite and epidote, and the turbid condition of the feldspars prove the rock to have undergone considerable alteration.

The microscopic structure of the rock remains tolerably uniform. Towards the margin of the mass, however, the texture is apt to become finer-grained, though this change is not always observable. At Porth-lisky, where the greater closeness of grain in the marginal parts is well seen, portions of the rock assume a structure approaching that of graphic granite, and are much veined with calcite. It is here that the bands of sparry carbonates described by Dr. Hicks occur. His so-called "quartz schists" are likewise portions of the graphic condition of the granite\*.

In the course of my study of crystalline rocks in the field, I have never met with the graphic structure except in veins. If the beach could be quite laid bare at Porth-lisky, it is probable that the graphic structure there visible might be found to belong really to veins connected with the main mass of the granite.

The same graphic structure is well displayed in the veins of lighter, finer-grained granite, or segregation-veins which traverse the main mass in so many places. These veins (known to German geologists by the glass-makers' term "Schlieren,"—threads or ribbons) are quite distinctive of granite, and do not occur among gneisses and schists. Their presence in the rock of St. David's is, in itself, sufficient to prove that rock to be an eruptive granite.

At the northern end of the ridge the granite is succeeded by masses of quartz porphyry. No continuous section can here be traced; but there are numerous exposures of rock between Bryn-y-garn and the valley near the cathedral. At Bryn-y-garn itself, the granite appears in its most typical form. A little to the north, at Rock House, what appears to the naked eye as an extremely small-grained granite, approaching to felsite, can be seen. At the bottom of the slope, on the roadside leading south-westwards from St. David's, a rock with still closer texture may be observed.

A series of thin slices prepared from these rocks leaves no doubt on my mind that there is here a transition from the granite of the

\* Quart. Journ. Geol. Soc. vol. xxxiv. p. 154. Professor Bonney observed the graphic structure in these rocks, though he was disposed to consider them as of metamorphic origin.

ridge into microcrystalline and spherulitic porphyry. The rock seen at Rock House is granitic in texture, and consists of the same minerals as the adjacent granite of Bryn-y-garn, but in smaller forms. The quartz and felspar, in a kind of granular micropegmatitic intermixture, constitute nearly the whole mass; but the chlorite is also present in tufted bright green aggregates. The rock on the roadside is still more finely crystalline. It forms a stage between granite and true felsite. Its ground-mass presents a microcrystalline aggregate of quartz and felspar, similar to that of the Church-School quarries, through which also spherulites are distributed. The same chloritic constituent so characteristic of the granite, is still recognizable here. Short of an actual section showing the gradations of the one rock into the other, I do not think that better evidence could be found that the granite is directly connected with the porphyries that lie along its border.

This intimate relationship is further illustrated by a study of the minute structure of the porphyries. Some of these rocks have been described in Dr. Hicks's papers by Professor Judd and Mr. Davies, and elsewhere by Mr. Tawney. Mr. Davies has shown the thoroughly crystalline nature of the ground-mass of the rock at the Church-School quarries. My observations not only confirm his description, but extend it to all the porphyry masses of the district. In none of them have I noticed any true felsitic base, though this may yet be found. Their ground-mass, between the spherulites to be immediately referred to, is entirely microcrystalline, and is resolvable into a granular intermixture of quartz and orthoclase. The rocks are quartz porphyries, but with a remarkable development of spherulites, which, following Vogelsang's terminology, are fels-spherulites. This spherulitic structure has been developed in altogether exceptional perfection and beauty (Plate X. fig. 9)—so much so, indeed, that the spherulitic quartz porphyries of St. David's are no doubt destined to become as classical examples of this structure, and as much sought after for collections of microscopic petrography, as the pitchstone of Arran now is for its microliths. They have been well described by Mr. Davies as they occur in the Church-School quarries\*. He has pointed out the want of peripheral definition of the spherulites in the rock at that locality, the absence in them of a central nucleus, and their tendency to group themselves round the quartz and felspar crystals. Instances, however, of sharp borders to the spherulites may be found in this rock, and still more conspicuously in the mass exposed at the centre of the cove below Nun's Chapel. The rock at the latter locality is finely spherulitic, the spherulites having a distinct dark border, and many of them standing isolated in the base. Though the base is somewhat decomposed, the spherulites are still tolerably fresh, and react in the usual way on polarized light, giving a distinct black cross between crossed prisms (Plate X. fig. 10).

The development of these spherulites is one of the problems which will require a more exhaustive study of the St. David's rocks, and the solution of which can hardly fail to throw light on the relations

\* *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 164, xxxv. p. 293.



between granite and lava-form rocks. I may observe in connexion with this subject, that while microcrystalline structure appears to run through all the porphyries, spherulites are not always present. In the dyke or elvan of Nun's Chapel, for example, while some portions of the mass are spherulitic, others are merely microcrystalline. The spherulitic structure, however, appears to be only exceptionally absent. It occurs not only in large elvans, like those of Nun's Chapel and the Church-School quarries, but even in small veins, such as that which traverses the agglomerate on Clegyr Hill and that which cuts across the tuffs near Pen-y-foel.

To the porphyries a distinctly porphyritic structure is given by the presence in them of abundant macroscopic quartz blebs or crystals. These are sometimes dihexahedral, usually with somewhat blunted angles; but they also assume irregular rounded forms, occasionally enclosing portions of the base. Porphyritic crystals of plagioclase are common in many of the rocks.

Some portions of the porphyries where these quartzes and felspars do not appear might be classed as felsites on a cursory inspection. But they all possess the microcrystalline ground-mass. They cannot be confounded with the felsites of which fragments occur in the tuffs.

Traces of fluxion-structure are discernible in the elvan of Nun's Chapel. The shales at that locality have been invaded by intrusive veins and bands of a rock now much decomposed, but which appears to have been a quartz porphyry. It consists of a decayed ground-mass with much diffused brown matter disposed in lines that sweep round the abundant large quartzes. If it was connected with the adjoining elvan it may show a further stage towards the development of a felsitic rock. But though I have had several slices made from my specimens, they show a rock rather too much decayed to warrant any deductions from them until better examples have been procured.

Proceeding now from their petrographical to their geotectonic characters, I have to remark that the porphyries occur as bosses, elvans, or veins cutting through all horizons of the volcanic group, and in one case apparently, if not actually, reaching the quartz conglomerate. One of the best exposures of this intrusive character may be seen in the cliff below Nun's Chapel, where the elvan, already so often referred to, runs along the face of the cliff through the uppermost zone of the volcanic group. On the whole its direction is parallel with the strike of the beds. That it is not strictly so, but that the porphyry cuts irregularly through the strata, is well shown at many places\*. On one conspicuous precipice the porphyry mass has a thickness of from forty to fifty feet, and lies at an angle of  $35^{\circ}$ , cutting through the strata, which are inclined, with reversed dip to the northward or towards the land, at from  $65^{\circ}$  to  $70^{\circ}$ .

Apparently in connexion with this dyke a network of intrusions of the peculiar decomposed quartz porphyry above referred to may be observed in the shales along the face of the cliff immediately below Nun's Chapel. On the whole the intruded material has forced its

\* Dr. Hicks has figured this intrusive mass (*Quart. Journ. Geol. Soc.* vol. xxxiii. p. 236).



way along the bedding-planes of the shales, but has also broken across them, sending out finger-like branches. At first I took the rock for a tuff; and it was not until I noticed that it was porphyritic with quartz, and that it intersected the shales, that I recognized its true character. Some portions are veined with, and contain lenticular seams of the siliceous substance to be immediately described, in which may be detected the doubly terminated quartz and the felspar crystals of the rock.

The association of quartz porphyry with granite is so familiar a fact as to need no further comment here. I would only add that in the granite district of Criffel and Galway there are masses of quartz porphyry presenting the closest resemblance to those of St. David's. Like the granite with which they are connected, they have risen through Lower Silurian strata.

I now come to the metamorphism that has attended the intrusion of the granite and porphyries. The district of St. David's is too limited in extent to furnish data for a full discussion of this subject. The facts there attainable ought to be extended by observations of the line of junction of the eruptive and sedimentary rocks in the rest of Pembrokeshire. I would therefore at present offer only such a slight sketch as the material in my possession seems to warrant.

The metamorphism traceable near the granite and quartz porphyries appears to consist partly in induration due to the introduction of new mineral matter, notably silica, into the strata, partly in the development of crystals or a crystalline rearrangement of the materials of the adjacent rocks.

In dealing with the amount of change superinduced upon stratified masses by granite which has been intruded into them, we have two factors in the question to consider—the petrographical structure and composition of the rocks affected, and the character and particularly the bulk of the eruptive mass. In regard to the first of these two points I may remark that quartz and quartzose rocks present little scope for metamorphic action. Secondary quartz may be deposited in their fissures, or between their particles; but unless they contain some silicate or other mineral matter which may be susceptible of recombination and recrystallization, they may show no further change than mere induration from introduced silica, or from the solution and recementing of their component grains.

With respect to the part played by the granite, it must be remembered that marked metamorphism does not always accompany intrusions of this rock\*. If the mass of granite be small, there may be

\* In this country examples may be found where little or no alteration is perceptible round the margin of the granite that has undoubtedly been erupted through the adjoining strata. Round the smaller granite bosses of Galloway this is observable among the more quartzose greywackes. The granite of Arran, though so large a mass, only slightly affects the surrounding rocks. On the continent numerous instances have been observed where no contact-metamorphism occurs round truly eruptive granite. My friend M. Renard has kindly supplied me with the following illustrations:—Petschau in Bohemia, where the contact of granite and shale is as sharp as if cut with a knife; Greifenheim; Ile de Michau (Côtes du Nord); banks of the Irtisch.

no distinct metamorphism at all. But even a large mass may produce little alteration. There seems to be some relation between the mineral constitution of the granite and the nature and amount of the metamorphism which it may superinduce\*.

The importance of noting these two conditions of the problem is well shown at St. David's. The granite mass there is but of small dimensions, and it is where it narrows into minor projections that its contact with the adjacent rock is chiefly exposed. These are precisely the circumstances under which only a feeble degree of metamorphism might be expected. On the other hand, where the rocks next the granite have not been much decomposed, they are found to be quartz conglomerate, or quartzose grit, in which little or no trace of alteration need be looked for.

The best natural section for noting the alteration produced by the granite is that exposed on the cliff at Ogof-llesugn. The conglomerate has there been indurated into the consistency of quartzite, breaking readily across the pebbles. The grits in the Allan valley have been similarly affected, but in a less degree. Microscopic preparations of these rocks show a structure like that of the quartzites of the Highlands. The quartz grains and pebbles have suffered no apparent change, except that in some places they have been much fractured. A deposit of secondary quartz may be observed running in veins through the rock. Where the pebbles have been fractured, disrupted portions are imbedded in a matrix in which, besides crystalline quartz, an indistinctly fibrous substance occurs, which may be chalcedony.

The shales and fine grits near the granite at Porth-clais are beautifully foliated, lines of the bright-green chloritic ingredient already referred to being especially prominent between the bands of quartz-grains. But, for reasons already given, I believe that this foliation has not resulted from the influence of the granite. At the same time there may be room for inquiry whether the effect of the granite may not have been to set up a new foliation, which, where it coincided in direction with the first, might intensify it.

From a specimen of fine shale or schist taken from near the granite on the right bank of the river, I have had several slices prepared. In these the first foliation is excellently shown; but the folia have been ruptured and shifted by, as it were, a series of closely parallel faults, along which a new but more feeble foliation has been developed by the production of a fine white mica (Plate X. fig. 8).

The alteration round the granite appears not to extend many yards away from the eruptive rock: but the sections are few and limited in extent; and in some places, owing to small local slips, the strata now abutting on the granite may have been originally at some little distance from it. In the case of the porphyries, however, the sections are far more numerous and extensive. The metamorphism associated with these rocks is also more marked. It consists

\* Professor Zirkel informs me that in his experience granites with white mica alter the surrounding rocks little, or not at all, and that it is the granites with black mica that produce most of the metamorphism.

in a partial bleaching of the rocks, in their induration into a flinty substance, and in the development of a microcrystalline structure in them. This alteration has been effected partly along the planes of bedding, and partly across them. The feeblest degree of change is marked by a slight induration of the shale or grit, the elastic nature of the rock being still obvious. From this condition successive stages may be traced until the rock appears in milk-white, flint-like masses, homogeneous, translucent, and breaking with a splintery to conchoidal fracture.

These changes are most conspicuously seen in the uppermost zone of the volcanic group, but are not confined to it. They appear wherever the porphyries have invaded the rocks. The best locality for their study is the coast-section at Nun's Chapel, where they attain a remarkable development in the zone of fine tuffs and shales below the quartz conglomerate. They are shown also among the corresponding strata at Ogfeydd-duon, on Ramsey sound. At first the latter locality seemed to be an exception to the rule that this kind of metamorphism is connected with the protrusion of the quartz porphyries; but, searching the ground in the neighbourhood, I afterwards found the prominent and massive porphyry crags of Treginnis. On a lower horizon the alteration has been well developed in the agglomerate of Clegyr, where also there are intrusive dykes of spherulitic porphyry. And, on a still lower platform, similar induration accompanies the quartziferous porphyry of the Board Schools. From the published descriptions, the association of highly siliceous bands (porcellanite, hälleflinta, kieselschiefer, adinole, or whatever they may be called) with masses of felsite and quartz porphyry would appear to be of common occurrence in Wales.

The sections that exhibit most clearly the metamorphism associated with the porphyries are those which have been cut by the sea along the coast from Nun's Chapel eastward. In the first stages of change the shales are indurated, begin to lose the distinctness of their bedding, and break with a splintery fracture. Gradually they become feebly translucent on the edge, like the porcellanite or kieselschiefer of contact metamorphism. The granular texture passes into one like that of hornstone, and the edges become more translucent, until, losing by degrees all obvious trace of elastic structure, the rock presents a translucency, fracture, and lustre like those of flint or chert. The colours of these various conditions of the siliceous material range through shades of dirty grey and bluish and greenish grey to milky white. The alteration having been developed more particularly along the bedding of the strata, the indurated layers appear mostly as bands interstratified with the schists, shales, or tuffs. So evenly, indeed, are these layers interposed that they may readily be regarded as original deposits, formed contemporaneously with the strata among which they lie. They vary from thin laminae to bands a foot or more in thickness. Some of them are regularly banded in alternate layers of more granular and more flinty texture. It is deserving of remark that, owing to the tilted position of the beds, the indurated bands are usually highly inclined or vertical, presenting occasionally



a resemblance to mineral veins. Traced along the strike, they are found to be lenticular walls imbedded in and shading off into shales and fine tuffs.

The material composing these vertical bands occurs likewise in nodules or concretions varying from the size of a pin's to that of a man's head or larger. These are particularly abundant in a bed of grey shale, the laminæ of which bend round them, as if nodules of some kind had lain there when the sediment was being deposited. A gradation in size and in development seems to be traceable among these included masses. In some cases they are represented by cavities lined with limonite. In proportion as they increase in size they grow more flinty in texture, until they assume the same pale milk-white translucent character found among the bedded masses. One of the concretions which M. Renard has kindly analyzed for me has the subjoined composition.

*Analysis of Concretion (Adinole) Nun's Chapel, St. David's.*

By M. Renard.

Si O <sub>2</sub> .....	78.62
Al <sub>2</sub> O <sub>3</sub> .....	13.67
Fe <sub>2</sub> O <sub>3</sub> .....	1.22
Mn O .....	trace.
Mg O .....	trace.
Ca O .....	0.30
K <sub>2</sub> O .....	0.26
Na <sub>2</sub> O .....	5.80
Loss	0.63
<hr/>	
	100.50

The layer of shale next one of the thick bands, or round a concretion, is frequently dull, dark green in colour, and compact in texture, so that on a wet face of rock the contrast between it and the adjoining pale indurated substance is well marked.

There is still a third form in which the same cherty material occurs. It may be seen ramifying through the shales in strings and winding veins, that strike across the stratification of the surrounding beds. It is there welded, as it were, into the shale, the laminæ of which pass into it. Faint lines may even be detected here and there passing across the veins in the line of the laminæ of the shale, on either side, as if they were a survival of these laminæ. In the veins, as in the bands and concretions, the portions next the shale are more granular than the central parts, which as before, become flinty, milk-white and translucent.

Dr. Hicks and Mr. Davies have compared these compact flinty aggregates with the hälleflintas of Scandinavia. They are undoubtedly products of metamorphism; and their chemical composition as well as minute structure probably varies from place to place. The rock, analyzed by M. Renard corresponds both in composition and in



petrographical characters with the petrosilex of Sala in Sweden, to which, as already remarked, Beudant gave the name of "adinole" \*.

The microscopic structure of some of the bands has been described by Mr. Davies and Dr. Hicks †. The latter author remarks that the chief peculiarity of the rock consists in the way in which the quartz is separated into nests.

In the slices which have been prepared in the Geological Survey laboratories the more granular varieties are evidently fine shales or tuffs, in which the clastic materials are quite distinct, though the matrix separating them shows an incipient, feebly developed microcrystalline structure. The more flint-like varieties display a more perfectly microcrystalline base. The constituents of the base appear to be chiefly feldspars and quartz. They are here and there aggregated into patches of coarse crystallization, among which large well-striated plagioclase is occasionally conspicuous. One of the most interesting slides was prepared from a pale, milk-white, flint-like mass, taken from the coast below Nun's Chapel. It presents the usual finely granular microcrystalline base, which remains of a pale bluish tint between crossed prisms. The slide is traversed by two parallel veins of quartz, one of which measures  $\frac{1}{10}$  of an inch in diameter and is quite visible to the naked eye. Other minute threads of the same substance appear under the microscope. The most remarkable feature in this quartz-vein is the fact that it is crowded with liquid inclusions, arranged in approximately parallel partitions which run across the breadth of the vein. Each inclusion has a bubble; and in some cases the bubbles rotate or vibrate as we watch them in the field of the microscope.

In trying to realize what has been the origin of these highly compact siliceous aggregates, we see that they have been specially developed among fine tuffs and shales or schists. From the analysis of the acid tuffs above given, it is certain that some bands contain above 70 per cent of silica; the specimen of adinole from Nun's Chapel, analyzed by M. Renard, contains, as we have seen, 78.62 per cent. of that ingredient. In some instances the whole of the silica may have been present in the rock before its alteration.

But whether or not silica has been subsequently introduced into the flinty bands of St. David's, it is evident that they cannot be due entirely to original deposition. In the first place the material of the bands and of the concretions is so precisely the same as that of the transverse and ramifying veins that we must connect the three modes of occurrence together as parts of one general process of alteration, and must conclude that, at least in their present condition, these microcrystalline aggregates must be later in date than the rocks in which they lie.

In the second place, the same flinty substance traverses the quartz porphyry of Nun's Chapel. In the veins which, in connexion with that rock, ramify into the adjacent shale, it is here and there conspicuous. One of my microscopic slides from the elvan itself

\* *Traité de Minéralogie* (2nd edit., 1832), vol. ii. p. 126.

† *Quart. Journ. Geol. Soc.* vol. xxxv. pp. 285 *et seq.*

shows a tendency towards the aggregation of granular crystalline quartz into nests and fine threads traversing the base, as if the quartz porphyry had been in some measure affected by the same process which has resulted in the production of the siliceous aggregations. Mr. Davies has also pointed out that in the felsite of Roche Castle abundant fissures filled with crystalline quartz occur, together with bands of fibrous chalcedony\*.

From the marked development of the siliceous microcrystalline aggregations near the dykes and bosses of porphyry, and their paucity or absence elsewhere, I infer that they are connected with the protrusion of that rock. That water was present, probably in considerable quantity, in the magma out of which the porphyries solidified, is shown by the liquid inclusions in the quartz of these rocks. Hot water or aqueous vapour no doubt continued to escape from the eruptive masses long after they had become solid. This water, probably sometimes charged with alkaline materials, sometimes with dissolved silica, would most readily escape along the highly inclined planes of stratification. Moreover the interstitial water present in the beds, or which might reach them from the surface, would come within the influence of the heat of the eruptive rock.

That the changes which produced the present microcrystalline texture and diffusion of quartz in these rocks took place in the presence of water, and under considerable pressure, is proved by the important fact to which I have referred, that the quartz of the fine veins that traverse the adinole is crowded with liquid inclusions with freely moving bubbles.

The presence of water being thus established, it is obvious that the nature of the metamorphism which it might set up would depend not only on its own chemical activity and that of the substances dissolved in it, but also upon the chemical composition of the rocks affected. Some of the strata must undoubtedly have been more liable to undergo alteration than others. Probably those which have suffered most, consisted originally of finely divided felsite dust. Such a condition would offer peculiar facilities for alteration by water under pressure. The presence of quartz-grains here and there in the sediment might determine the deposit of additional silica round these centres. The water permeating the rock would, no doubt, also fill the fine fissures with the same material. A crystalline re-arrangement of the felspathic constituents was likewise set on foot, with the result of producing a finely crystalline mass through which larger crystals, especially of plagioclase, have been developed. From the marked proportion of soda in the analysis of the adinole from Nun's Chapel, some of the felspar thus developed is obviously albite. We may suppose that the alkali was, in great measure, supplied during the process of metamorphism. The analysis further shows that there must be free silica as well as more alumina than is required for the constitution of the felspar.

The subject is too wide for adequate discussion here. But, from the data which I have now brought forward, it will be evident that

\* Quart. Journ. Geol. Soc. vol. xxxv. p. 291.

important additions to our knowledge of metamorphism may be looked for from a further study of the rocks of St. David's.

## 5. THE DIABASE DYKES AND INTRUSIVE SHEETS.

The latest rocks of the St. David's district are the dykes and intrusive sheets of diabase, which have been referred to in Part I. as traversing all the other formations. The dykes are specially abundant in the granite. One or two may be detected in almost every artificial opening which has been made in that rock; while on the coast-section they are here and there profusely abundant. They are likewise frequent in the quartz porphyries, as may be seen in the quarries near the schools, and still more conspicuously on the cliff south of Nun's Chapel, where, at a picturesque sea-worn cave, four dykes, varying from one to nine feet broad, cut through the elvan. They occur also in the volcanic group and in the sandstones and shales above the conglomerate, but become fewer in number as they recede from the granite centre.

In external characters, the rock composing these dykes and sheets may be described as usually a dull dirty-green or yellowish brown mass, to which the old name of "wacke" might appropriately be given. It exhibits the texture and mode of weathering of the more distinctly crystalline members of the basalt family. It is occasionally amygdaloidal or cellular, the kernels or cavities being arranged parallel with the sides of the dyke. Here and there a rudely prismatic structure extends between the walls.

To the descriptions of the microscopic structure of this rock already given by Prof. Judd, Mr. Davies, and Mr. Tawney I have but little to add. It is a diabase, but more allied in structure to true basalt than the olivine diabase of the volcanic group. It especially differs from the older rock in the abundance and freshness of its feldspars, in the comparative scarcity of its augite, and in the absence of olivine. The magnesian silicates are very generally replaced by green decomposition-products diffused through the mass. An occasional crystal of hornblende, recognizable by its cleavages and dichroism, may be detected.

I may add that some of these diabase dykes present excellent examples of fluxion-structure. Mr. Tawney noticed this in one of those traversing the granite at Porth-lisky\*. A thin slice which I have had cut from probably the same dyke, and showing the contact of the rock with the granite, reveals the streaming of the plagioclase prisms along the wall of the dyke. I have found the same arrangement in the narrow dyke that cuts through the shales south of Castell. But the most beautiful example among my slides was taken from a dyke in the shales, in a small cove to the east of Nun's Chapel. The shale and eruptive rock are in contact; and the small acicular prisms of feldspar, besides ranging themselves in lines parallel to the side of the dyke, stream round the larger feldspar crystals (Plate X. fig. 12).

\* Proc. Nat. Hist. Soc. Bristol, vol. ii. pt. 2, p. 115 (1879).



Some of the dykes or veins are only three inches broad. They send out fingers, and sometimes break abruptly across from one line to another. They appear generally to have followed the lines of joint in the granite, as Mr. Tawney has observed\*; consequently they must be posterior to the development of the system of jointing in that rock. In many places, particularly in the quarries in the Allan valley, between St. David's and Porth-clais, there is evidence of great pressure having been exercised on the rocks subsequent to the intrusion of the dykes; for the latter are much jointed and slickensided, and even a rude kind of cleavage may occasionally be observed in them.

Besides the abundant dykes, there has been a more limited extrusion of the same material in sheets parallel (or approximately so) to the bedding of the sandstones and shales. These sheets are well displayed at St. John's Point, where evidence of their being intrusive, and not truly bedded, may be seen along the fine cliffs which have been cut by the waves on this part of the coast-line.

## 6. CONCLUSION.

In concluding these observations, I may present a brief summary of what appears to me to have been the geological history of the St. David's district.

At some remote epoch in the Lower Cambrian period active volcanic vents, probably submarine, existed in the west of Pembroke-shire. From these vents successive showers of volcanic detritus and occasional streams of lava were emitted, until a pile of volcanic material at least 1800 feet thick had accumulated. Most of the discharges of dust and stones were due to the disruption of basic lavas; but at successive intervals copious showers of felsitic débris were also erupted. All the lavas poured out at the surface appear to have been of a basic character (olivine diabase). As volcanic activity died out, ordinary sedimentation was resumed, and the rest of the Harlech and succeeding groups of the Cambrian system were deposited.

At a later period the whole of these rock-groups, which had been laid down continuously without discordance, were subjected to disturbance, the principal effect of which was to throw them into an arch, and to bend over this arch into an isocline, with a general inclination towards the north-west. The strata likewise underwent a wide-spread foliation, which, in accordance with the structure and composition of the rocks affected, was chiefly developed in certain kinds of material.

Subsequent to these changes the south-eastern side of the fold was invaded by the rise of a mass of granite with the usual peripheral quartz porphyries. Accompanying and outlasting this intrusion, a process of metamorphism went on, the effect of which has been to change fine felsitic tuffs or shales into hard flinty translucent masses, and to superinduce in them a finely crystalline structure

\* Proc. Nat. Hist. Soc. Bristol, vol. ii. pt. 2, p. 115 (1879)



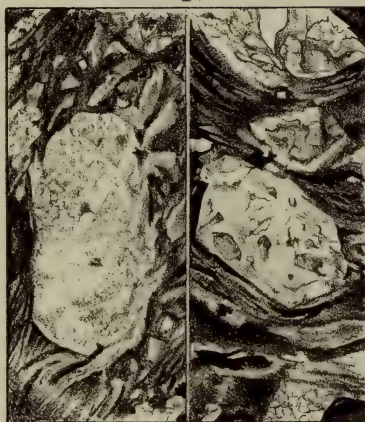




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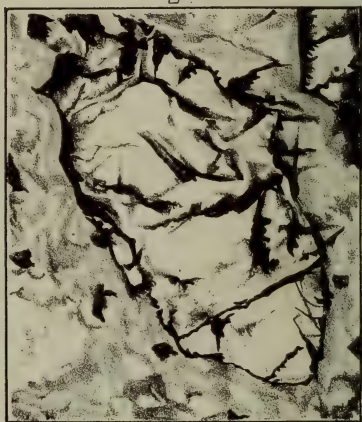
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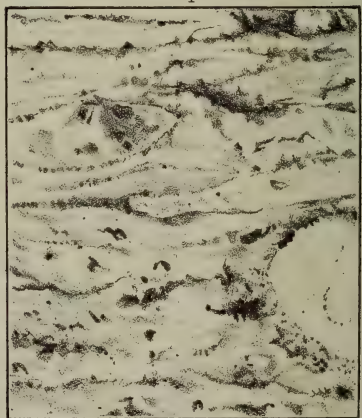
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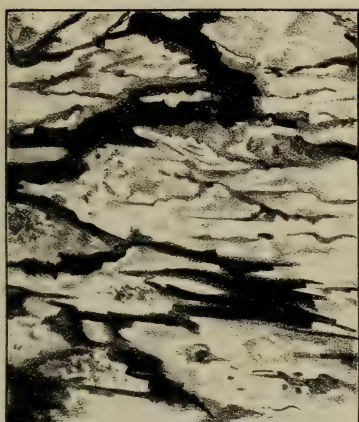


6.

T W Rudler, del ad nat.

Mintern Bros. lith.

ROCK SECTIONS. ST DAVID'S.



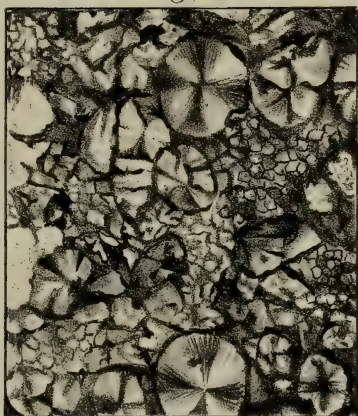
7.



8.



9.



10.



11



12







with the development of porphyritic-felspar crystals and veins and threads of crystalline quartz.

It is suggested for future inquiry whether the granite and accompanying porphyries can possibly represent the roots of any of the palæozoic volcanoes which played so important a part in the geological history of Pembrokeshire, as well as in the rest of Wales, during the Lower Silurian period.

The last episode is that of the diabase dykes, which represent the third and final outbreak of eruptive rocks in the St. David's district. These dykes rise particularly through the central core of granite, as through an old area of weakness. Whether they were connected with any outpouring of lava at the surface cannot be decided; nor does there appear to be any evidence that might lead even to an approximation to their relative geological date.

## EXPLANATION OF PLATES VIII.-X.

### PLATE VIII.

Geological Sketch map of the St. David's district (p. 268).

### PLATE IX.\*

- Fig. 1. Microscopic section of volcanic tuff, near Pen-y-foel, St. David's,  $\times 25$  diameters. (See p. 298.)
2. Ditto of fragment of lava in tuff, Pen-y-foel,  $\times 100$  diam. The large crystal shows the perfect form occasionally assumed by the augite in the lapilli of the basic tuffs. The finely cellular structure is also represented. (See p. 298.)
3. Ditto of band of tuff from red shales, with *Lingulella primæva*, Castell, Ramsey Sound, viewed by polarized light, with crossed nicols. The half marked A,  $\times 50$  diam.; that marked B  $\times 100$  diam. The portions here drawn were selected to show the way in which scattered felspars occur among the other lapilli. (See p. 299.)
4. Ditto of olivine diabase from near Pen-y-foel,  $\times 100$  diam., showing the remarkably well developed forms presented by the olivine. (See p. 304.)
5. Ditto of schist, roadside north of St. David's,  $\times 100$  diameters. The granular-shaded parts are the abundant green chloritic constituent, separated into elongated nests, between which the foliation is well marked. Here and there orthoclase, magnetite, or other mineral has crystallized out. (See p. 311.)
6. Ditto of schist, Ogfeydd-duon,  $\times 100$  diam. Among the constituents occasional rounded grains of quartz appear, as on the right-hand margin of the slide. (See p. 311.)

### PLATE X.

- Fig. 7. Microscopic section of schist, with crumpled folia, from roadside section north of St. David's,  $\times 100$  diam. (See p. 312.)
8. Ditto of schist, with refoliation, from Porth-clais,  $\times 25$  diam.

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\* The drawings from which these plates of microscopic structure have been prepared were made for me by my colleague Mr. F. W. Rudler, to whom my best thanks are due.

The older foliation is seen in the bands that run from the lower to the upper margin of the drawing. These bands have been disrupted, and a second feebler foliation has been developed along the lines drawn across the section from side to side. (See p. 318.)

- Fig. 9. Microscopic section of spherulitic quartz porphyry, from Board Schools, St. David's, viewed under polarized light, with crossed nicols,  $\times 25$  diam. (See p. 315.) One of the large quartz crystals appears in the upper left-hand corner. The beautifully perfect spherulites are surrounded by the microcrystalline base.
10. Ditto of spherulitic quartz porphyry, from below Nun's Chapel, St. David's, polarized light, crossed nicols,  $\times 100$  diam. This drawing (magnified four times as much as fig. 9) shows the structure of one of the more finely spherulitic porphyries, the very variable size of the spherulites, their isolation in the finely crystalline base, and the presence of rounded blebs of quartz, one of which appears on the left-hand margin of the drawing. (See p. 315.)
11. Ditto of granite from Bryn-y-Garn, polarized light, crossed nicols,  $\times 25$  diam, showing the distinctly granitic structure of the rock. (See p. 313.)
12. Ditto of a diabase dyke, showing fluxion-structure, from cove east of Nun's Chapel,  $\times 50$  diam. The upper part of the drawing marks the zone of contact between the diabase and the stratified rock; and immediately beyond it the numerous well-formed plagioclase crystals appear, first parallel to the wall and then streaming round what was originally a crystal, possibly of hornblende, but is now a mass of chlorite and other decomposition-products. (See p. 323.)

## DISCUSSION

(*On Part I., March 21, 1883.*)

The PRESIDENT remarked upon the great importance and interest of the subject discussed in the paper.

Dr. HICKS said that he commenced the study of these rocks in 1863, and afterwards carried on his researches in connexion with a former Member of the Geological Survey (Mr. Salter), and in consequence he was led to the discovery of the Menevian, Lower Cambrian, and other faunas. He disproved Sir R. Murchison's views that these fossils did not occur in the red rocks, and traced fossils down to the base of the Cambrian. He pointed out that the rock called by the Survey syenite, at Clegyr Hill, Nun's Chapel, and elsewhere, was a stratified rock, fragments of which occur as pebbles in the overlying conglomerates. He showed somewhat later that the ridge of crystalline or granitoid rocks, with its altered beds on each side, was Pre-Cambrian. Subsequently, with the aid of the late Prof. Harkness, Mr. Davies, and others, he was able to show that the granitoid rock was not intrusive, but had more the character of a metamorphic rock. The author of the present paper had mistaken some of his statements, which referred to N. Wales and Anglesey, as applying to St. David's. He thought that these so-called syenites had more of the peculiar characters of true granitoid rocks; and this was especially shown by their peculiar fracture.

He remarked on the general parallelism of the igneous intrusions along bedding-planes in great formations, and on their presence in the Dimetian as having a bearing on the probable strike in that formation. He proceeded to criticise the sections as given, which, he said, were not borne out by the actual facts, as he could vouch for from a thorough knowledge of the district. Professor Ramsay had agreed with him as to the great amount of faulting near Porth-clais; but Prof. Geikie admitted no faults. He instanced the special section cited at the Allan valley as illustrating the ignoring of faults by the author; and he produced specimens from the point to show there had been no alteration from the supposed intrusion. On the theory of intrusion, how could the presence of the conglomerates at Ogof-Llesugn be accounted for? These conglomerates are not more altered than those frequently found at a distance from the Dimetian; but the author had been deceived by the effect of crushing, and by an appearance due to the fact that the matrix was the recemented arkose-like material derived from the denudation of the Dimetian. With respect to the porphyry of Nun's Well, he had himself figured it as an intrusive rock, but had shown that it does not penetrate the Cambrian conglomerates. He pointed out that a large area of quartz porphyries near St. David's had been quite overlooked by the author; and that the great so-called intrusive band in the Survey Map of 1857 is made up of quartz felsites, breccias, and sedimentary beds, that its boundaries are incorrect, and, he was now compelled to say, that many other masses in the district are equally wrongly coloured and defined in that Map. The junction at Ogof-Llesugn and at Porth-lisky was clearly not an intrusive, but a faulted junction. At Porth-lisky the unconformity between Pebidian and Dimetian was manifest. On the western side of the district the unconformity of the Cambrian is proved by an overlap of the series below. The so-called tuff in the Cambrian he had examined, and found to be merely derivative from the underlying Pebidian rocks. Other bands he had shown to be intrusions along bedding-planes.

Mr. TOPLEY said that he had had the advantage of visiting the district with both Dr. Hicks and Mr. Geikie. He had great difficulty in discriminating between joints and so-called bedding-planes in the Dimetian and Arvonian when he visited the district with Dr. Hicks. He admitted many errors in the old Geological Survey Map, which are due to the hasty way in which it must have been constructed. He confirmed Mr. Geikie's views as to the section at Porth-clais. With regard to the Pebidian, Dr. Hicks admitted a general conformity of strike; and he (Mr. Topley) could not admit that the presence of a few fragments of the underlying volcanic rocks in the Cambrian quartzite conglomerate had the significance insisted upon by the advocates of the Pre-Cambrian. The author of the paper had shown the presence of contemporaneous volcanic tuff in the undoubted Cambrians. The same metamorphism has affected both the Cambrian and the underlying beds. He believed that Prof. Ramsay's old views would in the end prevail.

Mr. T. DAVIES found, on reexamining his sections of Dr. Hicks's



rocks, that he had nothing to withdraw. He protested against the rock in question being called granite. It had neither the mineralogical composition nor the structure of granite. Many of the supposed quartzite pebbles, on careful examination, proved not to be such, but a rock similar to Dimetian granitoid rocks.

Mr. PEACH maintained that the Survey had never mapped the beds at Nun's Chapel as syenite, and insisted that many of Dr. Hicks's supposed facts would not bear examination. It was not true that they recognized no faults. At Ogof-Llesugn the conglomerate was found welded with and kneaded into the granite.

Prof. HUGHES said he would not criticise the details of the boundary-lines, but confine himself to the larger question. He pointed out that in this, as in other similar areas, there was at the base of the Cambrian a group of rocks which, for our present purpose, might be conveniently divided into two series, an upper volcanic series and a lower gneissic series. Where the gneissic series consisted of alternations of granitoid rock, true gneiss, and schists, however pierced by elvans and other intrusions, it was possible to make out the strike; but where, as at St. David's, the granitoid rock was developed at the expense of the schistose portions, it was impossible to say which of the divisional planes coincided with original bedding, and often difficult to feel sure about the simply metamorphosed and the intruded portions.

If these were the result of extreme metamorphism of the lowest portion of a volcanic series, it was natural that they should be variable, and that the next overlying series should be of irregular character and occurrence. Higher up in the group there were beds of ordinary volcanic ejectamenta less altered.

These types, in some form or other, were generally found in every Archæan area in Britain.

The Cambrian basement beds rested irregularly on various parts of this Archæan group, and contained fragments of the older rocks, as might be seen in the conglomerate south of Clegyr, not always chiefly of the immediately underlying beds; for that depended upon the drift of the shingle. The granitoid rocks, being the lowest, were less exposed, and so furnished less of the material; and that was readily broken up and decomposed, so as to form a kind of Arkose, which resembles and sticks close to the granitoid rocks when it rests on them. He thought that there was an Archæan group at St. David's cut off by an enormous break from the Cambrian.

Professor BONNEY stated that, putting aside minor points, there were three main questions on which he would venture a few remarks. First, as regards the Arvonian group of Dr. Hicks, he had for some time both entertained and expressed the opinion that Dr. Hicks had been unfortunate in creating this formation, because in it he had included rocks of very different characters, and probably very different ages. Secondly, as regards the "Dimetian" of St. David's, two points were raised by the author touching the nature and the age of the rock. It was no doubt most difficult to decide whether the rock was igneous or metamorphic. Some of



the arguments formerly relied upon by Dr. Hicks to prove its metamorphic origin were certainly untenable; but that was admitted by Dr. Hicks himself, so that the Director-General had merely stated what was well known to most petrologists. At the same time there was a something, hard to describe in words, that differentiated this crystalline rock of St. David's from all the undoubted granites with which the speaker was acquainted, and he still thought it probable that it, like the granitoid rock of Twt Hill, Llanfaelog (Anglesey), Edcal Hill, &c., was really metamorphic. Next, as regards its age: he had carefully examined two out of the three sections relied on by the Director-General to prove the intrusive nature of the rock. Of intrusion he had been unable to see the slightest evidence, whether at Porth-clais or Ogof-Llesugn. The appearances at the latter place were undoubtedly difficult to explain; but an intrusion of the Dimetian appeared to him a most improbable suggestion. Further, the present materials of the Cambrian conglomerates of Dr. Hicks had evidently been derived from the destruction of quartzo-felspathic rock, and the quartz-grains corresponded remarkably as to their cavities &c. with the quartz-grains in the Dimetian. The microscopic structure of this conglomerate bore a singular resemblance to that of some conglomerates in North Wales which had been proved to be formed out of the ruins of a more ancient granitoid rock. Hence it was almost certain the Dimetian was older than the conglomerate. Lastly, as regards the separation of the Pebidian from the Cambrian, to himself there appeared to be an unconformity at the base of the quartz conglomerate; certainly there was an entire change in the lithological character of the deposits. In the Pebidian volcanic material predominated, the finer detrital beds were more indurated, and there was an incipient metamorphism. The conglomerate introduced a series of beds different in aspect, colour, materials, and condition. He did not say, and never had thought, that the break between Cambrian and Pebidian was necessarily a very great one; but it was perhaps as good physically as that between Upper and Lower Silurian, and, at any rate, a better physical break than could be found anywhere between itself and the Llandovery. Hence he must consider the two cardinal points of the Director-General's paper to be "not proven." Some mistakes, most of them already admitted, he had detected in Dr. Hicks's work; but considering the date and the circumstances it was a very small discredit to have erred occasionally.

Prof. LAPWORTH thought that in the stratigraphical part of the subject the author had failed to prove his point with regard to the intrusion of the granitic rock. The supposed intrusions appeared to be nothing but overturn faults, such as occur in all old crumpled districts. He asked if the name Cambrian was to be carried down indefinitely. He had found rocks resembling these Pebidian volcanic beds underlying fossiliferous Cambrian strata in Central England and round the Longmynd.

The AUTHOR said that he was placed at a disadvantage by his paper being split up into two portions; the second part would reply

to many of the objections. He disclaimed any idea of charging Dr. Hicks with acting unfairly ; he thought he had made a mistake. M. Renard agreed with himself as to the non-gneissic character of the so-called Dimetian. He thought Dr. Hicks would himself be prepared to give up the Arvonian. He saw no reason why fossils should not be found in stratified volcanic tuffs of the so-called Pebidian. The conglomerates do not contain the characteristic rocks of the St. David's district. He deferred further reply till his second part was read.

#### DISCUSSION

(*On Part II., April 11, 1883.*)

THE PRESIDENT asked for a calm and judicial discussion of the weighty problems treated of in the paper.

DR. HICKS stated that since the last meeting he had revisited the district with Prof. Hughes and ten excellent trained observers from Cambridge. This examination confirmed to the fullest extent the views expressed by Prof. Hughes and himself at the last meeting, and it proved also that the supposed facts relied upon by the author to support his views were clearly mistakes made by the author from an imperfect acquaintance with the district and the rocks. By the admission of the author the appearances are abnormal in the St. David's area. With respect to the intrusive character of the so-called granite, he asked what had become of the materials displaced by the intrusion. He regarded the so-called tuffs alternating with the Cambrian conglomerates as derivative rocks, full of quartz-grains &c. The junction of the sedimentary rocks with the granitoid rock was a faulted and not an intrusive junction. The fault was marked by slickensides, but not by any contact metamorphism. He demurred to the author's views as to the double series of foliations. He showed that while a dyke of greenstone 50 yards wide had produced enormous alteration in the surrounding rocks, the great granitoid mass had produced no alteration. At Ogof-llesugn, a place specially referred to by the author, it was possible to get between the Dimetian and the quite unaltered Cambrian conglomerate. Another mass of conglomerate was jammed in through the action of a fault. The amount of faulting and crushing in this area was enormous—a fact which did not seem to have been recognized at all by the author of the paper. The supposed porphyries in the Pebidian were really for the most part indurated ash. The author now admitted that unconformity existed between the Pebidian and the Cambrians. Examined with more care than appeared to have been given to it by the author, the conglomerate was found to consist in *very large part* of the Pebidian rocks, and of derivative materials from the still older Arvonian and Dimetian series. This fact was remarkably confirmed in Ramsey Island. He maintained the existence of a great unconformity between the Pebidian and the Cambrian conglomerates, the materials of the former having been meta-

morphosed before the deposition of the latter. He pointed out the existence of great masses of agglomerate in the midst of the supposed intrusive masses.

MR. PEACH stated that, taking Dr. Hicks's own sections, published in the Quart. Journ. Geol. Soc. vol. xxxiv., it was clear that the strata are repeated by a great inverted fold, and the beds can be identified member by member (from Dr. Hicks's description) on the two sides of the axis. From these sections of Dr. Hicks's he argued that the Cambrian conglomerate rests always on the same member of the underlying beds, and there could be no unconformity. He regarded the so-called Pebidian pebbles as segregations and not pebbles.

MR. HUDLESTON stated the results of an examination made of the district in 1877 in company with Dr. Hicks and the late Mr. Tawney. At that time Dr. Hicks had not recognized the volcanic origin of the Pebidians. No one could suppose the Pebidians to be of sufficient importance to constitute a system by themselves; and the great question was whether they should be grouped with the Cambrian or the Archæan. He had difficulty in recognizing the supposed unconformity between the Cambrian and the Pebidian, and he thought that the volcanic series was the natural base of the Cambrian system.

MR. TEALL called attention to the fact that diabase dykes in the granite were represented on Prof. Geikie's map as terminating at the junction with the Cambrian. He asked if this did not imply that they were Pre-Cambrian and of the age of the diabase tuffs.

MR. TOPLEY in reply stated that the faults invoked by Dr. Hicks would account for the non-passage of a dyke from the granite into the Cambrians. Dr. Hicks had not distinguished between local and regional metamorphism. The specimens from the conglomerate exhibited by Dr. Hicks were certainly exceptional; but the great mass of the conglomerates are of quartzose character. Local and small unconformities between the Cambrian conglomerates and the main volcanic group (Pebidian) had been admitted both at this and at the last meeting; but he differed from Dr. Hicks as to the great significance to be attached to them.

DR. CALLAWAY objected to Prof. Geikie's views as to bleaching and induration being proofs of local metamorphism; he regarded them on the contrary as evidence of faulted junction, the result of pressure and the infiltration of water. He did not think Dr. Hicks was justified in insisting on the Arvonian formation. He remarked that the key found by Dr. Hicks at St. David's had supplied us with an explanation of most of the similar Archæan series in England and Wales, which was a great confirmation of the truth of the theory.

MR. RUTLEY said that some of the felsites of the district resembled certain spherulitic rhyolites. He thought that they represented a transition between granitic rocks and ordinary rhyolitic lavas. Most of the Welsh lavas of the same kind with which he was acquainted were of Lower Silurian age.

MR. T. DAVIES could not agree with the author in regarding the so-called Dimetian as a granite. It contained no mica, nor had it



contained any ; for he could not regard the green mineral as the result of the alteration of mica *in situ*, but rather as derived from the interbedded basic rocks. Among 500 specimens of granite from about 400 localities he could find nothing resembling the St. David's rock, and he could not regard the latter as a granite at all. A rock in the very heart of this supposed intrusive mass was found to be a breccia with fragments (some of them waterworn) of the stratified rock of the district.

Prof. RENARD said that he had had a collection of specimens and of microscopic slides from the rocks of St. David's submitted to him by the author, and had examined them in concert with Professor Zirkel, of Leipzig, and Professor Wichmann, of Utrecht. The conclusions arrived at regarding them were as follows :—

1. The so-called " Dimetian " rock of St. David's is unquestionably a true granite.

2. The quartz porphyries are just such rocks as might be expected to occur as apophyses of the granite ; and the specimens from Brynny-Garn, Rock House, and St. David's left no doubt on our minds that such is really their origin. They cannot be confounded with rhyolitic lavas.

3. The conglomerate from the granite-contact shows secondary quartz between its pebbles.

4. The bands of fine tuff found intercalated with, and on various horizons above, the conglomerate, consist of true tuff, and cannot have been derived from the mere superficial waste of older volcanic rocks.

5. Fine foliation is well developed among the strata above the conglomerate as well as in the volcanic group below.

Mr. T. DAVIES did not admit that some of the rocks cited by M. Renard were granites at all.

Mr. J. A. PHILLIPS had found in the St. David's rock something which much resembled a crystal of mica undergoing alteration into epidote.

Prof. BONNEY stated that his remarks at the last meeting were founded upon a knowledge of the whole argument of the paper, which he had read through as Secretary, but that he would now criticise a few details in the present part. He thought that there were in North Wales volcanic materials in positions similar to those at St. David's. He criticised some of the mineralogical details of the paper, pointing out that the presence of the so-called sericite proved very little either way. The quartz porphyries might, no doubt, be extensions of a granitic mass ; but granitoid rock in North Wales and at the Wrekin was distinctly cut by rather similar quartz porphyries. For himself he thought that on the whole the conglomerate made a good base for the Cambrian ; and he felt certain that whatever the so-called Dimetian might be, it was older than the Cambrian conglomerate.

The AUTHOR pointed out that certain sections of Dr. Hicks were not only incorrect but quite impossible. Dr. Hicks had put in faults in the most reckless manner ; but, granting them, they did not dis-



prove the author's views as to the relations of the beds. Dr. Hicks's views as to the remanié character of the tuffs alternating with the conglomerate were contradicted by the careful study of Drs. Zirkel and Wichmann and M. Renard. Dr. Hicks had been recently to St. David's, but he was quite unable to produce a pebble of Dimetian from the Conglomerate. He controverted Dr. Hicks's views as to the section at Ogof-llesugn. He stated that the diabase dykes cut through both the granite and the Cambrian conglomerate of the district, though they are most abundant in the former. In reply to Prof. Bonney, he stated that microcline was regarded by continental workers as characteristic of granite rather than of gneiss. He asserted that none of the conclusions of his paper had been shaken by the discussion. He disclaimed all wish to interfere in this controversy in the first instance; but it was from a sense of duty that he came forward and defended the views of his predecessors.

20. *On the SKULL of MEGALOSAURUS.* By Prof. OWEN, C.B., F.R.S.,  
F.G.S., &c. (Read April 25, 1883.)

[PLATE XI.]

SINCE the description of the fossils on which the genus and species (*Megalosaurus Bucklandi*) was founded \*, the additional specimens have been, mainly, parts of the trunk and limbs. To the mandibular and dental fossils have been added two portions of the upper jaw, now in the Oxford Museum, on which Professor Phillips has founded the restoration of the skull given in Diagram lvii. of his 'Geology of Oxford' †.

Acceptable, therefore, were the additional cranial and dental evidences obtained by Edward Cleminshaw, Esq., M.A., F.G.S., of Greenhill, Sherborne, Dorset, from the freestone of the 'Inferior Oolite,' near Sherborne ‡. Blocks of this stone were in course of preparation for a building, when, indications of imbedded fossils being detected by Mr. Cleminshaw on fractured surfaces of the quarry-stones, he withdrew all such from the building-yard and transmitted them to the British Museum for identification.

Further requisite development of these remains having been there carried out, the following descriptions and drawings are now submitted to the Geological Society.

In the section devoted to the genus *Megalosaurus* in vol. i. pp. 329-354 of the undercited work §, the materials for a reconstruction of the skull were limited to portions of the mandible and divers teeth therein implanted or detached. The most instructive of these was a portion of the lower jaw, in the collection of His Grace the Duke of Marlborough, from the same formation (Oolitic Slate, Oxford) as that which had afforded Buckland the materials for the species which bears his name. The other localities, yielding the detached teeth figured in my '*Dinosauria*,' plate 33, were the 'Corn-brash' of Oxfordshire, the 'Bath Oolite' of Somersetshire, and the 'Wealden' of Sussex ||.

The differences shown by the mandibular specimens were limited to size—the vertical diameter of the deepest part of the type mandible being  $3\frac{1}{2}$  inches, while that of the Blenheim specimen gave  $4\frac{1}{2}$  inches. But as the teeth retained in these mandibular pieces

\* Buckland (Rev. Wm., F.R.S., G.S.), "Notice on the *Megalosaurus*," &c., in 'Transactions of the Geological Society of London,' 2nd series, vol. i. 1824, pp. 390-396, plates xl.-xliv.

† 8vo, 1871, p. 199; see also Prof. Huxley, Quart. Journ. Geol. Soc. vol. xxv. 1869, p. 311, pl. xii.; and Prof. H. A. Nicholson, 'Ancient Life-history of the Earth,' 8vo, 1877, p. 249.

‡ 'Dorset County Chronicle,' June 15th, 1882, "Report of a Meeting of the Dorset Natural-History and Antiquarian Field Club."

§ Owen, British Fossil Reptiles, 4to, 1855.

|| *Ibid.* p. 351.

were of the same size, as well as form and structure, there was no ground for predicating distinction of species.

In the Blenheim specimen I was permitted to expose the germs and portions of the successional teeth concealed in the substance of the mandible\*.

Before entering on the description of the first of the present series of fossils which demonstrates cranial characters not hitherto determined, I may premise that existing Saurians show differences in the degree of ossification of the outer wall of the facial part of the skull.

In Crocodilia it is entire from the relatively small orbit behind to the smaller single nostril in front; and there is no break in that wall in modern and tertiary species, answering to the antorbital vacuity in Liassic genera; but this opening, recalling the antorbital nostril of *Ichthyosaurus*, is very small and is margined by the maxillary, lacrymal, and nasal bones.

In existing Lacertians much difference is seen in this character; but in none is the face so completely ossified as in the Crocodiles. The Monitors (*Thorictes*, *Tupinambis*) come nearest thereto, the nostril being divided from the orbit by a broad triangular facial plate of the maxillary, supplemented behind by a narrow malolacrymal one. In *Lacerta* the lacrymal enters in larger proportion into the formation of this part of the bony face, and the external nostrils are relatively wider. In *Iguana* the facial wall dividing the nostril from the orbit is relatively narrower, and the apex of the maxillary process is further removed by a large interposed lacrymal from the nasal bone. But in the Lacertians with a carnivorous dentition (*Hydrosaurus*, *Varanus*) the outer bony nostrils are remarkable for their great relative size, especially length; and the maxillary sends upward and backward a long but narrow pointed plate, which, in *Varanus bivittatus*, crosses in front of a small lacrymal bone to articulate with the prefrontal.

Here we attain the cranial modification which forms the best guide to the interpretation of the appearances presented by the fossil, the subject of Plate XI. fig. 1, and restored on a Varanian type in the Cut, p. 340.

But, before entering on this comparative survey, I may note the corresponding degree of resemblance which the skull of *Iguanodon* presents to those of the herbivorous and mixed-feeding Lacertians, *Iguana* and *Thorictes*, with correspondingly adaptive shapes of the teeth. In the relative size of the external nostril *Iguanodon Foxii* resembles *Tupinambis* more than it does *Iguana* with the larger nostril; and the side wall between nostril and orbit is relatively broader and more extensive in *Iguana* than in either of the blunt- or thick-toothed Lacertians. I may remark also that, as usual in the larger forms, the orbits are relatively smaller than in the dwarfed kinds.

In all the Lacertians here compared, teeth are developed from the whole (*Iguana*, *Tupinambis*), or nearly the whole (*Hydrosaurus*, *Varanus*), of the alveolar border of the maxillary; consequently this

\* See 'Remarks' thereon in the volume above cited.

dental series extends beneath both nasal and orbital vacuities, but for a less extent in the carnivorous than in the herbivorous Lacer-  
tians. *Scelidosaurus*, in the degree and kind of its facial ossifica-  
tion, repeats the mammalian character exemplified in *Iguanodon* \*.

Of the subjects of the present paper the first block of lower  
oolitic freestone includes a great proportion of the right side of the  
facial part of the skull (Plate XI. fig. 1). The missing parts are  
the fore end of the premaxillary, 22', and the hind or suborbital  
end of the maxillary, 21'; the upper and hinder pointed termination  
of the facial process, *f*, of the maxillary, is likewise wanting.

The length of this facial fossil is 1 foot  $3\frac{1}{4}$  inches; its height from  
the upper angle, *a*, of the maxillary process to the tip of the sub-  
jacent tooth *t*, *in situ*, is 9 inches.

Of the premaxillary are preserved part of the nasal process, 22'', and  
so much of the alveolar part, 22, as lodges two fully developed and  
protruded teeth and the socket of a third: an intervening part of  
the bone has been chiselled away to admit a wedge for the quarrying-  
operations; the length of the preserved premaxillary nasal process,  
22'', is 4 inches, the breadth of its base is 1 inch; it narrows to its  
apex, being limited to the fore and under part of the large bony  
nasal vacuity, *n*, in the present specimen.

So much of 22'' as is preserved forms rather more than one third  
of the lower border of the external nostril, *n*, the rest of that border  
with the hinder boundary, *a*, being contributed by the maxillary,  
21''. The limitary suture between these bones is distinct.

The preserved length of the alveolar part of the maxillary, 21, 21',  
is 1 foot: the upper border of this part contributes an equal share  
to the large nasal (*n*) and orbital (*o*) vacuities; but these portions of  
such tooth-bearing part of the upper jaw combine to form the base  
of the facial process, *a f*, which is between four and five inches in  
extent: its breadth, at one inch above the border line, 22'', is three  
inches; this breadth is nearly preserved to the angle, *a*, about six  
inches above the alveolar border, at which angle the maxillary is  
continued backward, above the fore part of the orbit, gradually  
narrowing to the point, *f'*, which is here broken off.

Much of the outer wall of the alveolar part of the maxillary  
adheres to the block of freestone in which the counterpart of the  
above-described cranial fossil is preserved: but this counterpart  
shows only the impressions of the teeth, which are well preserved  
in the block containing the chief part of the fossil. Of these teeth  
four are premaxillary, the rest maxillary.

The teeth closely repeat the characters of previously described  
dental evidences of *Megalosaurus Bucklandi*.

Of the foremost preserved premaxillary tooth, 2 inches of the crown  
remain, with half an inch of a mutilated base; the next tooth is re-  
presented by a smaller protruded apical part of the crown. The socket  
of the larger intervening tooth is broken away with the implanted  
tooth-root, exposing the pulp-cavity. The impression of the broken

\* Monograph in the volume of the Palæontographical Society for the year  
1861, tab. v. fig. 1.



and missing part of the smaller premaxillary tooth gives two inches of length to this tooth; the implanted remainder of both teeth has gone with the supporting bone. In advance of the larger premaxillary tooth is an elliptical cross-fractured basal part of a third (the anterior) tooth, showing a long diameter of nearly half an inch.

Ten teeth are preserved in the maxillary bone. Between the foremost, third, and fifth are crowns of successional or undeveloped teeth. Of the foremost of these (second in the series) the apex only of the crown has appeared above its socket; the rest of the tooth is exposed by removal of the socket's outer wall: a length of enamelled crown of 2 inches 5 lines is thus shown. The length of the protruded crown of the first maxillary tooth is 1 inch 9 lines; that of the third tooth is 2 inches 3 lines; its total length is 5 inches. Of the fourth tooth the apical half-inch of the crown is protruded: the total length exposed in the quarrying is  $3\frac{1}{2}$  inches. The similarly shown length of the fifth tooth is 4 inches 9 lines, that of the enamelled crown being 3 inches. The sixth tooth shows 2 inches of free enamelled crown, and  $2\frac{1}{2}$  inches of the rooted cement-clad part, the latter exposed by loss of the bone. The seventh maxillary tooth is represented by a smaller proportion of the protruded crown. The eighth tooth is a functional fully developed one, but of smaller size than the third and fifth. The apical half of a somewhat smaller crown of a ninth tooth has emerged; and behind this is the indication of a fully developed tenth tooth, not larger than the eighth. I cannot predicate with confidence the existence of an eleventh maxillary tooth. The crown of such exposed tooth on the transversely fractured surface of the block may have come from the lower jaw.

Of the maxillary teeth the four or five hinder ones are suborbital, the three front ones are subnarial; the three intermediate teeth, including those with longest and largest crowns, received the support, in biting action, of the base of the facial process, *a*.

At the fore part of the orbital cavity are two thin osseous plates, *e, e*, convex outwardly, of subtriangular form, with the apex naturally cut off so as to contribute half the circumference of a protruding circular space, half an inch across, exposing the matrix: the margin of this circular aperture is slightly raised. These plates show, or have been resolved into, three lamellæ, each less than a millimetre in thickness: part of one lamella, and an impression of another, are shown on the slab containing the teeth and bones; parts of three lamellæ of one of the plates adhere to the counterpart block. The matrix near what seems to be the pupillary border is stained of a darker colour than the rest. I deem it probable that we have here an indication of the eye-ball of the Megalosaur, and that the pupillary corneal part of the ball was strengthened by a few large sclerotic plates. The indicated diameter of such eye-ball is two inches. The attention devoted to this part of the fossil was requisite to determine whether it might be part of a lacrymal bone or of the sclerotic.

The orbit in its great relative size and departure from the usual

circular form finds, amongst existing Saurians, its nearest approach in the large carnivorous Varanians. The comparatively small size of the eye-ball accords with the hugeness and carnivory of the extinct terrestrial Dinosaur.

An indication that the lower jaw had been enclosed, with the portion of the upper one above described, in the same mass of matrix, is given by the impression of the crown of the mandibular tooth projecting into the interval between the third and fourth maxillary teeth, in the block exposing the upper jaw, the tooth leaving that impression being preserved in the counterpart block. The extent of the mandibular tooth so preserved measures 1 inch 8 lines, and includes the upper two thirds of the crown: the breadth of the fracture is 8 lines; and this exposes the termination of the pulp-cavity.

I infer therefore that the portions of mandible with teeth next to be described are not only Megalosaurian, but formed parts of the same individual as the preceding fossil. They were worked out of separate blocks of freestone which were in contiguity prior to the masonic operations.

The first portion shows the outer side of the anterior ten inches of the right mandibular ramus, a portion of which, two thirds the natural size, is shown in fig. 3. The vertical diameter of the bone is  $2\frac{1}{2}$  inches at two inches distance from the fore end, and  $2\frac{3}{4}$  inches at the opposite fractured end. The symphyseal profile is obtusely rounded or moderately convex, as shown in the restoration of the skull (Cut, p. 340). The foremost tooth rises at half an inch therefrom. This tooth gives an exerted length of crown of  $2\frac{1}{4}$  inches, with a basal breadth of 9 lines. An interval of nearly one inch divides it from the second tooth, also fully developed, but with the apical half of the crown broken away. The third, fourth, and fifth mandibular teeth rise at similar intervals; and only the fifth falls short of full protrusion, the upper two thirds of the crown appearing above the alveolar border. The base of a sixth tooth, with a large formative cavity, is discernible, with the usual interval between it and the fifth. So much of the outer surface of the bone as remains indicates a shallow longitudinal groove, nearly midway between the upper and lower margins, and disappearing beneath the second tooth in place: anterior to this the bone shows a few irregular shallow pits, some of which, occupied by matrix, indicate nervous or vascular foramina. In the same block are two fragments of probably the left ramus of the same jaw, each in connexion with, or lodging, a portion of a fully developed tooth.

A larger portion (fig. 2), which has been freed from another block, consists of the anterior part of the left mandibular ramus of the same skull, 8 inches in length, but wanting the symphyseal end. On its outer side it repeats the longitudinal groove, here extending backward three inches beyond the part interrupted in the right ramus. In advance of this groove there are similar depressions and indications of the small nervo-vascular foramina. As the lower border of the present fragment begins to bend upward at the anterior

fracture in a degree similar to the fore end of the right ramus, I conclude that not more than an extent of two or three inches is wanted to complete that end. The oblique fracture of the bone here exposes the hollow base of the crown of a functional tooth; and on its inner side is the partially calcified germ of the successor.

The inner surface of the ramus (fig. 2) is flatter and smoother than the outer. It is traversed by a deeper, narrower, and better-defined longitudinal groove—partially divided at its hinder half by a low linear ridge, indicative of the groove having been traversed by two impressing soft parts, probably a nerve as well as a vessel. The main groove becomes shallower and wider as it advances, inclining from the middle to near the lower border of the inner surface. Part of the suture between the splenial (31) and dentary (32) elements is here seen.

The teeth indicated in the portion of the left ramus have been more or less broken away, but answer in number and relative position to the entire ones in the right ramus. The tooth rising to fill the space between the first and second is more advanced; and on the inner side of the present fragment are seen the crown-tips of other successional teeth, appearing at the inner side of the base of preserved portions of the fully developed teeth. At the intervals of these rising teeth are seen the “series of triangular plates of bone (*b*, *b*, fig. 2), forming a zigzag buttress along the interior of the alveoli, and from the centre of each triangular plate the bony septum which crosses to the outer parapet and thus completes the alveolus,” well described in the type example\*.

As respects the dental characters exhibited in the present series of fossils, I find nothing to add to the discoverer's original and graphic descriptions and to the supplementary details afforded by the more complete mandible and teeth in the private collection of the Duke of Marlborough at Blenheim†. In the restoration of the skull I have been guided by that of the largest existing carnivorous land-lizard (*Varanus giganteus*); and it may prove that the post-orbital part of the skull is somewhat too short in the Cut, p. 340. Moreover the present fossils impress me with the notion that they have come from a rather smaller individual than those yielding the subjects of the under-cited plates‡. But on these data and subsequent materials I estimate the total length of the skull of *Megalosaurus Bucklandi* not to have exceeded 2 feet 6 inches; they certainly do not support that of “four or five feet” ascribed to it by Professors Phillips and Alleyne Nicholson.

The opportunities of supplementing the original indication of the great extinct carnivorous Saurian having been few and far between, may condone the details above recorded of the additional elements toward its restoration here submitted.

I conclude with some general remarks to which their study, in

\* Buckland, *loc. cit.* p. 395, pl. xl. fig. 1.

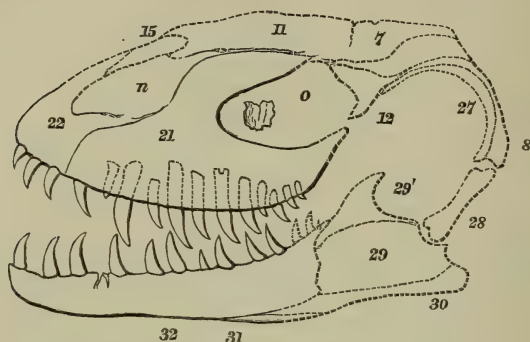
† ‘History of the British Fossil Reptiles,’ 4to, vol. i. pp. 348–352.

‡ *Ibid.* Dinosauria, pls. 24–32.



connexion with previous communications on the same subject, has given rise.

*Restoration of the Skull of Megalosaurus.*  $\frac{1}{10}$  nat. size.



The restored portions are indicated by broken lines.

Hermann v. Meyer, in his folio 'Zur Fauna der Vorwelt, Reptilien aus dem lithographischen Schiefer' (1859), affirms "the beak (upper jaw and mandible) of the Pterodactyles to be formed, as in birds, by a single bone, the intermaxillary;" which bone he held to be "prolonged backward to the region of the orbits" (*ibid.* p. 15); and the sole modification which he admits, in the avian comparison, is that of a greater density of the bone, in relation to its sustaining and wielding teeth instead of being sheathed with horn (*ibid.*).

Prof. Huxley sees, or surmises, the same structure in the portion of the skull of the *Megalosaurus* described in the 'Quarterly Journal of the Geological Society,' vol. xxv. p. 311; and, similarly, he founds thereon an argument for the affinity of the great terrestrial Saurians to the class of birds\*; but, as will be presently shown, there are other and truer grounds for that affinity.

From the evidence of the premaxillo-maxillary suture (Pl. XI. fig. 1, s, s) in the present mature skull, it is improbable that such suture should have been obliterated in the Oxford cranial specimen, the mutilated condition of which might condone a conclusion supposed to support a favourite hypothesis. The primitive separation of the maxillary and premaxillary bones is retained throughout life in the existing reptiles nearest akin to *Megalosaurus*. The conjecture, therefore, that the jaw figured in plate xii. *tom. cit.* is simply the premaxillary, "a possibility which must not be lost sight of, in view of the resemblances between *Dinosauria* and Birds" (*ib.* p. 312), has no support from fact, nor needs it.

In his remarks, Prof. Huxley, with Hermann v. Meyer, holds that the upper jaw in birds is formed by a premaxillary which is "prolonged backward to the region of the orbit." A portion of the

\* Quart. Journ. Geol. Soc. vol. xxvi.



slender continuation of the jaw, answering to part of that in the subject of the present paper (Plate XI. fig. 1, 21'), which is so prolonged, appears at *c* in plate xii. *tom. cit.*

Concomitantly with the superior development of the circulating and respiratory organs and their vigorous action in the Avian class, the obliteration of the boundaries of bones takes place earlier, and, among Vertebrates, is most complete in birds. But one result of my researches in the osteogeny of the class was, that in no species was the premaxillary produced backward to beneath the orbit, but that such portion of the upper jaw is contributed by the maxillary bone \*. In *Dinornis ingens* the maxillo-premaxillary suture is retained †; so likewise in *Aptornis*: in these great wingless birds, with somewhat lower locomotive, circulating, and respiratory activities, the ossific process is retarded.

So the experienced ornithotomist Dr. Schufeldt writes:—"The malar is the mid style of the infraorbital bar, the maxillary completing the connexion anteriorly with the intermaxillary." "It simply requires ordinary maceration in the adult of any of the Grouse or Quails to have the three styles separate from each other" ‡.

Pterodactyles show a larger proportional size of the premaxillary than do either *Iguanodon* or *Megalosaurus*; but neither in *Dimorphodon* nor any other of its order, in which the maxillo-premaxillary suture can be unequivocally traced, does the premaxillary extend backwards beneath the orbit.

In this respect birds agree with Pterodactyles; but as regards the affinity which is held to amalgamate the two groups, the question has always presented itself to my mind in the following condition:—It is true that Pterodactyles flew, and birds fly; but their organs of flight are not only different, but the differences throw light on those of other organs of much greater, indeed of real, importance in forming a judgment as to their class-affinities.

In birds the main mechanical part of the wing is due to cuticular developments, in reptiles to cutaneous ones; in the one 'Appendages of the Integument,' in the other 'Extensions of the Integument' itself, are pressed into the formation of the organs of flight. In birds the 'remiges,' or feathers of flight, are supported and wielded by short and thick bones; in Pterodactyles the dermal webs are sustained by long and slender bones.

The main condition of these modifications of wings is the temperature of the body which the two kinds of flyers are, or were, capable of maintaining: in one kind it is fixed; in the other it varied to a certain extent with that of the atmosphere. In no class of Verte-

\* See 'Archetype and Homologies of the Vertebrate Skeleton,' 8vo, 1848, p. 128, fig. 23, 21, 22; 'Anatomy of Vertebrates,' vol. ii. p. 51, figs. 26, 28 (young Ostrich), fig. 31 (young Emu), fig. 30 (Parrot).

† 'Extinct Wingless Birds of New Zealand,' 4to, 1878, vol. ii. pl. lxxxiii. fig. 1, 21, 22.

‡ See his plate v. fig. 51, showing the remoteness of the premaxillary from the suborbital region, in his 'Contributions to the Anatomy of Birds,' 8vo, 1882.

brates is the heat of the body maintained at so high a degree as in that of Birds: in Mammals it rarely exceeds, and not always reaches 100° Fahr.; in Birds it ranges, according to species, from 106° (*Apteryx*) to 112° (Eagle).

This thermogenous character involves a tegumentary one. The body-warmth of a Mammal is protected, as a rule, to which bats are no exception, by a covering of wool or hair, or both, the body-warmth of a bird by a clothing of down and feathers; and it is the latter that are pressed into the mechanism of the organs of flight; and their presence is demonstrated by impressions in a suitable matrix of the secondary extinct species of the class\*.

If he had never had a recent bird to dissect, the physiologist would have inferred, and rightly, that the heart had partaken, in its structure, of all the perfections which characterize that of the warm-blooded mammalian class; and he knows, *ex visu*, that it superadded structures, in the muscularity of certain of the heart-valves, which relate to the higher activities of the bird. Concomitantly do the organs of respiration manifest their highest grade of development. Not only are the lungs, as in Mammals, "spongy," *i. e.* subdivided into multitudinous minute cells, multiplying the surface on which the pulmonary capillaries are exposed to the oxygenating atmosphere, but other cells are continued from the lungs proper, and submit, in different degrees, the systemic capillaries to the action of the air inhaled. So birds are said to enjoy a double respiration as well as circulation.

In no reptile is the arterial blood, as it is returned from their large-celled lungs, distributed pure and unmixed with venous blood to the general system†; in none is the function of respiration so complete, so extensive, as in the warm-blooded classes. Impressions of the sheets of skin have been preserved, which the long and slender finger-bones of the Pterodactyle were destined to support; but not a trace of non-conducting hair or protecting feather has been detected therewith in any, the most conservative, beds.

I consequently infer a correlated inferiority of structure in the circulating and respiratory systems, and that the Pterodactyles were as cold-blooded as are the flying fishes and the flying insects: therefore I prefer the term *Pterosauria* to *Ornithosauria*.

Never, however, have I excluded considerations from other organs and functions in treating of the affinities of the Vertebrate animals recent and extinct. They weighed with me, mainly, in my endeavours to interpret the nature and structure of the sacrum in *Megalosaurus*, and the affinities so indicated.

In Buckland's time (1824) no exception to the number two in the reptilian sacrum had been recognized; he consequently described the "five anchylosed joints of the vertebral column of the *Megalosaurus*, as

\* "Archæopteryx," Phil. Trans. 1863, pp. 33-47.

† For the partial degree in which the respired or arterial blood may be so transmitted from the left ventricle of the Crocodile's heart, see 'Anatomy of Vertebrates,' vol. i. (1866) p. 512.

including the two sacrals and two others, which are probably referable to the lumbar and caudal vertebræ”\*.

Baron Cuvier, incorporating Buckland’s discovery in the concluding volume of his ‘Ossemens Fossiles,’ refers to the figure cited below as “Suite de cinq vertèbres de *Megalosaurus*”†, without further definition.

In determining the nature and class of these five coalesced vertebræ as truly “sacral”—and that determination has been accepted—I did not indicate, as has been alleged, any affinity therefore to the class *Mammalia*, but proceeded to unravel the structure of the sacrum, and demonstrated that it was such as occurred in no *Mammal*, but was repeated in the class of *Birds*.

Now, the condition to which I have referred, which has deceived such able palæontological osteologists as Von Meyer and Huxley in regard to the construction of the upper jaw in *Birds* and *Pterodactyles*, and by inference in *Megalosaurs*, the speedy confluence, viz., of essentially distinct bones and bony elements in *Birds*, constituted the main difficulty to be overcome in the correlation of the peculiar and, at that time, unique structure of the sacrum of the *Megalosaurus* with that of the many-vertebrated sacrum in other classes.

In the extinct reptile the neurapophyses, in each vertebra, were shifted in position from their proper centrum so as to cross the interspace of two centrams; and I had to determine to which of these centrams the neural arch did properly belong. The mammalian class was exhausted without result; the avian class presented the difficulty of the complete blending of the several sacral vertebræ with other pelvic elements into a single mass of bone.

The resource (fossils of great wingless birds not having then come under my ken) was investigation of the development of the sacrum of a bird; and that line of research was not abandoned until I could testify with certainty to that class of vertebrates repeating the singular modification in the great terrestrial extinct *Reptilia*‡, thence and thereupon associated together as *Dinosauria*.

No other affinity is deduced from the discovery save of the *Dinosaur* to the *Bird*. The result of the embryonal researches is limited in the ‘Report’ § to that inference. The labours leading thereto are detailed in the work ‘On the Archetype of the Vertebrate Skeleton’ ||.

In my Hunterian Lectures at the Royal College of Surgeons ¶, after defining the class-characters based on the circulating and respiratory systems, I took occasion to remark:—“But many im-

\* Geol. Trans. 2nd Series, vol. i. (1824) p. 395, pl. xliii. fig. 1.

† Tome v. 2<sup>de</sup> partie (1822), p. 348.

‡ “Report on British Fossil Reptiles,” Part ii. ‘Reports of the British Association for the advancement of Science,’ vol. for 1841, pp. 105-108.

§ Ib. ib.

|| 8vo, 1848, “Composition of the Sacrum in Birds,” in which the congeries of vertebræ in that of an immature *Ostrich* is the subject of figure 27, p. 159.

¶ Anatomy of Vertebrates, vol. i. 1866, pp. 6 & 7.



portant relations and affinities are thereby masked. Although the last two classes (Mammalia and Aves) agree as 'hot-blooded Vertebrates' in their higher cerebral development, and in the more complex heart and lungs, Birds, by their genetic and developmental characters, as well as by the general plan of the organization, are more intimately and naturally allied to the oviparous Saurians than to the viviparous Mammals."

So, likewise, I proceeded to state that "in their generation and development, modern Batrachians differ from other cold-blooded air-breathers and agree with fishes: both classes are 'anallantoic' and branchiate, whilst Birds and Reptiles are 'allantoic and abran-  
chiate' " \*.

The occipital condyle offered no available character in this division and association of vertebrate animals. The condyle is single in most fishes as in the abran-  
chiate Ovipara; and it is convex in some kinds, *e. g.* the Pipe-fishes (*Fistularia*) †, as in Birds. On the other hand the occipital condyle is double in the batrachian air-breathing Anallantoids or Branchiates, as it is in Mammals.

In short, in the preliminary chapter of my 'Anatomy of Vertebrates,' I found no other than the developmental characters above cited to add to those which John Hunter, in the previous century, had defined in his 'Schemes of the Classification of Animals.'

They are given in the 'Essays and Observations on Natural History,' published with notes in 1861 (two vols. 8vo, Van Voorst, vol. i. p. 28); and the subjoined quotation may be acceptable.

"Of the similarity of many Parts of the Fowl and Three-cavity-hearted Animals" (which Hunter termed *Tricoilia* = Reptiles).

"The lungs of the fowl open into thin cells or bags that are in the cavity of the belly. The cells of the lungs are large. The lungs in the *Tricoilia* are continued into the belly, are cellular at the upper part, but in most, *e. g.* the snake, become smooth bags at the lower end as it were, answering the same purpose as the abdominal bag in fowls: the cells of the lung-part are large.

"No proper diaphragm in either class, but fowls have something similar to one." (The degree in which it most nearly attains the mammalian character is shown in my "Anatomy of the Apteryx," Zool. Trans. vol. i.)

"The gall is green in both. The kidneys are placed in what may be called the pelvis in both; they are conglomerated in a particular manner, have the ureter ramifying through their whole substance, and it enters into the rectum. The urine is a chalky substance in many of both classes, and is a kind of slime in others.

"The testes are situated in the abdomen in the males of both. The vasa deferentia enter the rectum in both. The penis is grooved in both. Both are oviparous.

"The structure of the ear is similar" (p. 28).

To these characters I added the subsequently determined develop-

\* 'Anatomy of Vertebrates,' tom. cit. p. 7.

† Tom. cit. p. 7.



mental ones, viz. the presence of an allantois and the non-development of branchiæ.

By what Hunter defined as "lungs in the neck, called 'Gills,'" he characterized his 'Fourth Class;' and, in reference to the two poles of the 'Amphibious' division of the 'Fourth,' he observes, in his quaint style, that they are "more fishified than what the fish of the first class (*Cetacea*) are," *op. cit.* p. 27. De Blainville, entertaining similar views, proposed, in 1816, the name *Ornithoidea* for the abbranchiate, *Ichthyoidea* for the branchiate group\*.

The terms which Professor Huxley has invented for the two groups previously defined and characterized by Hunter and myself are as convenient as De Blainville's; but it seems odd to speak of a Lizard as a "Sauropsid," when it is not only like, but is, a Saurian, or to call a perch an "Ichthyopsid," which is not merely like, but is, a fish. The terms "Abbranchiates" and "Branchiates" appear to me to express an essential character of the two groups without suggesting any absurdity.

Returning to my proper subject, I would, finally, remark that, in the summary of what I had learnt on fossil Reptiles in 1841, the respective outward resemblance in the different orders to existing vertebrate classes was briefly indicated—Pterodactyles to birds, Ichthyosaurs to fishes, Dinosaurs to mammalian quadrupeds, &c. But this was in no wise intended, or could be fairly construed, to prejudice conclusions as to affinity founded on structure; and those which demonstrated the truer and deeper relations of Dinosaurs to birds were given in detail in 1841 †. As to the dental and limb-resemblances of extinct Saurians, I have since been enabled to show that a group of triassic *Reptilia*, the *Theriodontia* of the Karoo formation, make a nearer approach to *Mammalia*, especially the marsupial forms, than the later mesozoic Dinosaurs do, in outward character ‡.

Professor Huxley, however, asserts, in the Quarterly Journal of the Geological Society, vol. xxvi. part 1, p. 13, *note*, that "Prof. Owen evidently attached no weight to the fact as indicating any affinity of the Dinosauria with birds, as in his 'Report on British Fossil Reptiles,' 1861, p. 102, he says that 'the Reptilian type of structure makes the nearest approach to Mammals in the Dinosauria.'"

Other Fellows of the Society, besides myself, have been puzzled to verify this statement; and I have therefore added a summary of what I did record ten years previously, and I have never changed my opinion, of the near approach to Birds which the reptilian type of structure makes in the Dinosauria, and more especially in the genus and species which is the subject of the present paper.

\* Nouveau Bulletin des Sciences de la Société Philomathique, 1816.

† 'Reports of the British Association' for that year.

‡ In summing up the characters of Theriodonts I did not omit to notice that their "sacrum was not limited, as in existing Reptiles, to two vertebræ, but was composed of five or six anchylosed vertebræ" (Quart. Journ. Geol. Soc. 1876, p. 99). But this in no way affected the structural resemblance of the sacrum of Dinosauria to that of birds, pointed out a quarter of a century before.

## DESCRIPTION OF PLATE XI.

## MEGALOSAURUS BUCKLANDI.

- Fig. 1. Side view of the premaxillo-maxillary, or facial part of the skull, rather less than one half natural size.
2. Inner side view of portion of the left mandibular ramus, two thirds nat. size.
3. Outer side view of portions of upper and lower jaws, with teeth, two thirds nat. size.

## DISCUSSION.

The PRESIDENT expressed the pleasure of the Fellows in seeing Prof. Owen among them at this meeting. He had himself listened with the deepest interest to this extremely suggestive paper, but would limit his remarks to the subject indicated by the title of the paper, viz. the skull of *Megalosaurus*. He thought that if it was impossible by the regulations of the British Museum to place the actual remains before the meeting, it was much to be regretted that one of the excellent casts taken by Mr. G. M. Barlow, the sculptor of the Palæontological Department, had not been placed upon the table. *Megalosaurus* was, in a certain sense, the property of the Society, as it was in a communication made to it by the late Dean Buckland that this Dinosaur was first brought under the notice of palæontologists. Besides this paper, and that by Prof. Huxley, both mentioned by the author, and the latter's valuable description of Megalosaurian remains in the 'Fossil Reptilia,' he would call attention to Eudes Deslongchamps's exhaustive and accurate account of *Poikilopleuron Bucklandi*, in the 'Memoirs of the Linnean Society of Normandy,' because there can be no doubt that this Saurian was a member of the genus *Megalosaurus*. It should be borne in mind that the genus *Megalosaurus* is not represented by the single species *Bucklandi*, but there exists evidence of several species, notably the very large series of Megalosaurian remains in the collection of Mr. James Parker, of Oxford, which certainly illustrates two distinct species. With respect to the skull, a premaxillary in Mr. Parker's collection (poorly figured by Phillips in the 'Geology of Oxford') distinctly shows the extent to which this entered into the composition of the snout. In the author's restoration a lower temporal bar was omitted; but as this is present in the skull of every Dinosaur in which this part of the skeleton is known, viz. in *Iguanodon* (as illustrated by *I. Mantelli*), in *Hypsilophodon*, and in *Scelidosaurus*, he thought its presence highly probable in *Megalosaurus*; he would suggest also the probability of a greater extension backwards of the roof of the cranium, and a more vertical direction and greater stoutness of the quadrate bone.

Prof. SEELEY spoke of the difficulty of discussing a paper of such wide grasp; for, in this memoir, Prof. Owen had gathered up the threads of many lines of research. Prof. Owen had now cleared up uncertainties as to the form of the premaxillary bone; but the idea of the blending of that bone with the maxillary had for

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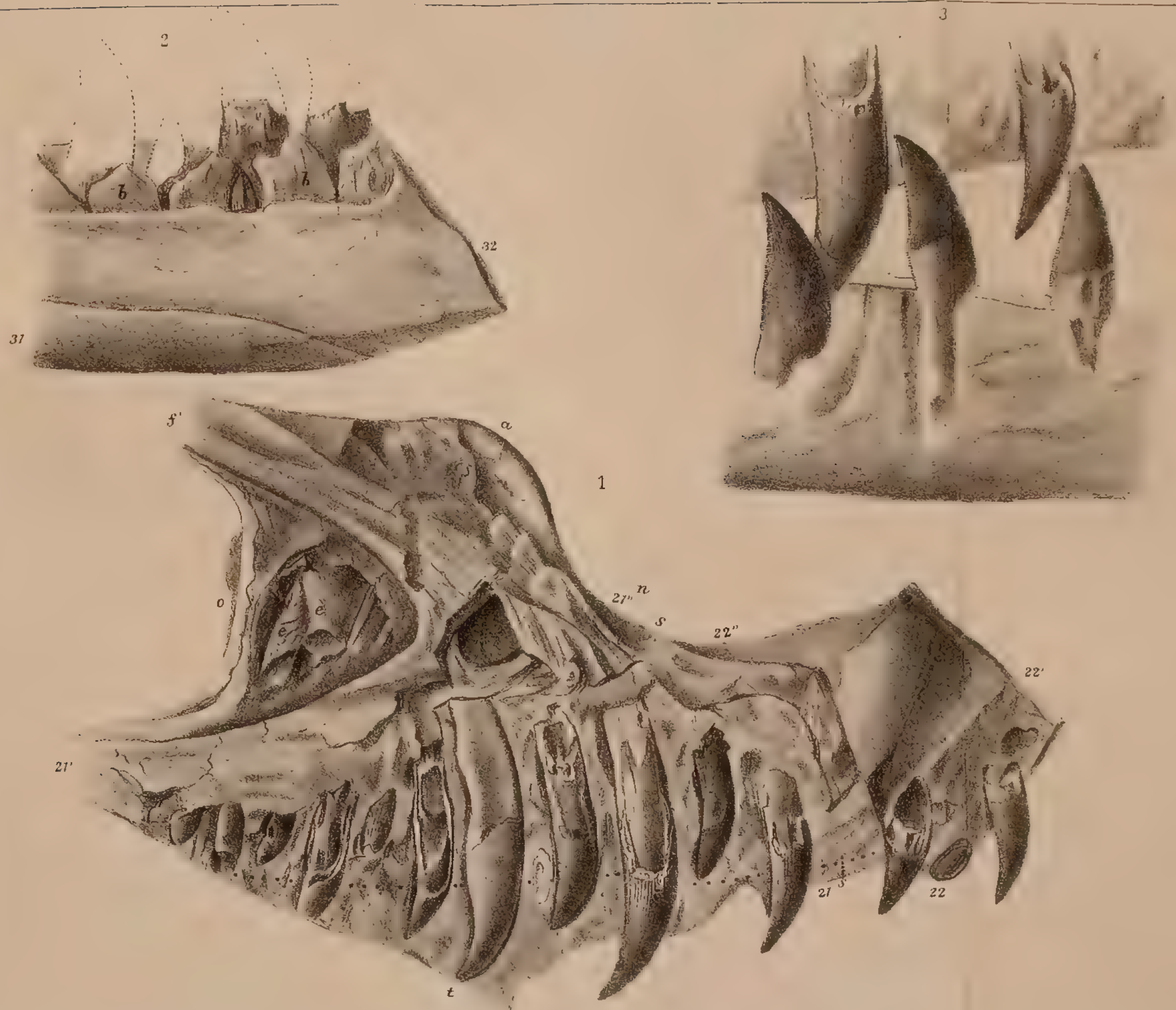


22'











some years been given up by palæontologists. Several bones in these specimens had been noticed by Prof. Owen which had certainly escaped the observation of others. He believed that the complete skull would show a curious combination of Lacertilian and Avian characters, such as might result from growth of the cerebral region in an embryonic Crocodilian type. He thought the figure represented, in the back part of the head, too wide a divergence from known Dinosaurians. Up to the present time he had had a very imperfect conception of the relation between the premaxillary bone and the maxillary in the Ornithosauria. He held that the Ornithosauria need not be cold-blooded because no trace of an exterior covering to the integument could be detected. He thought some trace of a filamentous covering could be detected. Their structures appeared to him to agree in so many respects with those of birds that he thought Ornithosaurs must have been warm-blooded.

Prof. OWEN expressed his sense of the kind way in which his communication had been received. It was to some extent polemical; but his excuse was that the last attempt to add to our knowledge of *Megalosaurus* was in vol. xxvi. part 1, of the 'Quarterly Journal;' and there the author had made statements concerning his (Prof. Owen's) views as to the relations of Dinosauria which were not exactly correct.

21. *The BAGSHOT BEDS of the LONDON BASIN.* By HORACE W. MONCKTON, Esq., F.G.S. (Read April 25, 1883.)

THE opening of several new railways during the last few years has greatly increased the opportunities for studying the geology of the Bagshot district. The railway-cuttings, however, are rapidly becoming overgrown or obscured by fallen materials, and I think that a description of some of the sections may interest the Society. In compiling these notes I have been greatly assisted by Mr. Herries; and the lists of fossils are from our joint collection.

*The Lower Bagshot beds*, 100 to 150 feet thick, consist of yellow and white siliceous and micaceous sand, without green grains, with beds of greyish sandy clay, often laminated, and with more or less distinct vegetable impressions. On the western borders of Bagshot Heath the base of these beds is marked by

- (a) Coarse, often ferruginous sand, occasionally laminated with nearly white clay and sometimes with pieces of wood.
- (b) Irregular and extensive masses of rolled flint pebbles.
- (c) Dark-coloured stiff clay, named Ramsdell clay by the Geological Survey.

*The Upper and middle Bagshot Sands* of Prof. Prestwich, consist of a series of the very persistent and well-marked beds shown in the following table:—

Upper Bagshot of Geological Survey.	Upper Bagshot of Prestwich. 226 feet or more.	A. Yellow siliceous sands with great numbers of casts of shells, often well preserved.	Shells of Lower Barton species.
		B. Yellow siliceous sands with a few green grains and casts of shells, few and ill preserved. Beds A and B are 226 feet or more thick.	
	Middle Bagshot of Prestwich. 40 to 60 ft.	C. Pebble bed, more or less regular and of variable thickness, in a greenish or ferruginous sand. 10 to 18 inches.	Shells of Bracklesham species.
		D. Yellow and greenish sands with ferruginous layers and light-coloured foliated clays. 10 to 20 feet.	
		E. Very fine green sand, with subordinate dark clay and lignite. Fossils abundant. Average about 20 feet.	
		F. Laminated clays, often black or liver-coloured, with beds of impure green sand, lignite, and plant-remains. 15 to 20 feet.	
Bracklesham beds of Geological Survey.			



The railway-cuttings at Goldsworthy Hill, at Ascot, and at Wellington College afford good type sections in the lower part of these beds, and show that the above subdivisions, though varying in thickness, are very persistent. The Goldsworthy-Hill section was described by Prof. Prestwich in 1847 (Quart. Journ. Geol. Soc. vol. iii. p. 382).

The subdivision C in the above table is there represented by a "coarse greenish sand with a few flint pebbles" two feet thick; the subdivision D by Prestwich's bed 2, foliated clays eleven feet; E by his beds 3, 4, 5, eighteen feet; and F by his beds 6 and 7, fifteen feet thick.

A very similar section was opened a few years ago on the branch of the South-Western Railway between Ascot and Bagshot,  $7\frac{1}{2}$  miles north-west of Goldsworthy Hill. Starting from Ascot station, the line passes over Lower Bagshot Sand for about three quarters of a mile; the middle Bagshot clays then come in, and are well shown in a brick-field close to the railway. This brick-field was described in the Memoirs of the Geological Survey (vol. iv. p. 332); but subsequent excavation has greatly improved the section.

The overlying fossiliferous beds are exhibited in an adjoining cutting on the railway, which was measured by Mr. William Herries and myself in 1879 (Geol. Mag. iii. p. 171); it is now much overgrown.

*Section on the South-Western Railway, near Ascot.*

	ft.	in.
B* 1. Fine light-yellow sand.		
2. Yellow sand with layers of darker-coloured iron-sand .....	2	6
C 3. Pebble-bed, with rolled flint pebbles in iron-sand matrix often greenish .....	0	10
D 4. Yellow sand with layers of iron-sand, passing into a finely foliated sandy clay, with patches of yellow and greenish sand ...about	10	0
5. Layer of flint pebbles .....	0	2
E 6. Yellow and liver-coloured foliated sandy clay .....	3	0
7. Green sand with a little dark clay, casts of shells abundant in a layer of yellowish sand .....	8 or 9	0
<i>Fusus longævus</i> , Lam.; <i>Fusus</i> , ? sp.; <i>Voluta</i> , ? sp., like <i>V. cithara</i> , Lam.; <i>Pleurotoma</i> , ? sp.; <i>Natica</i> sp.; <i>Turritella sulcifera</i> , Lam.; <i>Phorus agglutinans</i> , Lam.; <i>Ostrea flabellulum</i> , Lam.; <i>Pecten corneus</i> , Lam.; <i>Cardita carinata</i> , ? Sow.; <i>C. planicosta</i> , Lam.; <i>Cardium porulosum</i> , Brand.; <i>Protocardium semistriatum</i> , Desh.; <i>Cytherea nitidula</i> , Lam.; <i>C. suberycinoides</i> , Desh.; <i>Corbula gallica</i> , Lam.; <i>C. striata</i> , Desh.; <i>Gastrochana corallium</i> , Sow.; <i>Serpula</i> , sp.; and wood.		
F 8. Clays and clayey green sand, shown in a brick-field near the railway, where the beds exposed are:—		
Liver-coloured and yellow clay laminated with white and green sand.		
A wedge-shaped bed of green sand.		
Nearly black foliated clay with iron pyrites, vegetable impressions, and wood, 18 to 20 ft.		

FINE WHITE LOWER BAGSHOT SAND.

At Hagthorn Hill,  $\frac{3}{4}$  mile to the north-west of the above brick-field, there is a pebble-bed 2 feet 6 inches thick, apparently in nearly the same relative position as that numbered 3 in the railway-

\* The letters in this and the following table refer to the table, p. 348.

cutting section. The mass of stones is here such as to be worth quarrying.

An almost precisely similar succession is shown in the series of shallow cuttings on the South-Eastern Railway, near Wellington College Station, which are shown in the annexed cut (p. 351). The following are the details:—

*Section on the South-Eastern Railway, near Wellington College.*

Gravel.

- B. Light yellow sand, with small patches of green sand, casts of shells, numerous but very imperfect, including species of *Fusus*, *Natica*, *Phorus*, *Turritella*, *Voluta*, wood, &c. .... 50 ft. or more.
- C. A greenish sand, with two irregular lines of flint pebbles, and a few pebbles of old rock ..... 1 ft. 6 in.
- D. Yellowish sand, iron-sand concretions, and layers, a few casts of *Turritella*, and wood..... Thickness varies, 2 to 4 ft.  
 Yellowish, reddish, or greenish sand, with numerous thin laminae of light-coloured clay ..... About 15 ft.  
 [This bed was until recently worked for bricks at Wellington College.]  
 Dark-coloured laminated clay, with an irregular line of flint pebbles. 3 to 4 ft.
- E. Green sand..... Thickness not shown.
- F. Dark laminated clay, with a little impure greensand. (This bed is shown in a pit at Upwick or Wick Hill near Finchampstead.)  
 Lower Bagshot Sands, yellow clayey sand, with beds of stiff laminated clay, which are worked for brick-making at California near Finchampstead, and are there wrongly marked "Middle Bagshot" on the Geological Map.

The above examples establish, I think, with sufficient certainty, the succession of the strata in this district; and the well-sections at Wellington College and the Albert Asylum, Bagshot (Mem. Geol. Surv. iv. pp. 425, 537), are very similar. In all a pebble-bed appears at the top of the clayey beds, and affords good evidence of a break in the series at this point.

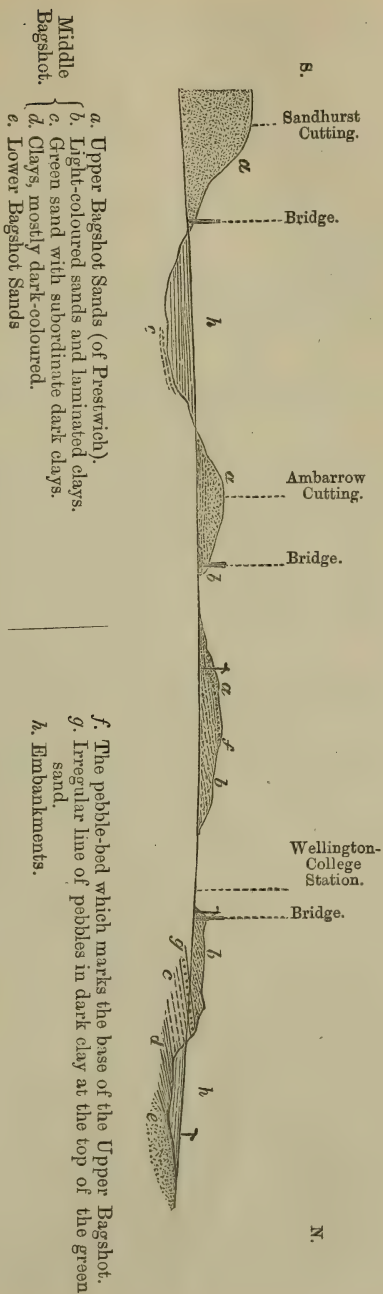
With the exception of the Albert-Asylum well, there is no section through the whole of the upper sandy beds lettered A and B in the table of strata; and it is therefore not easy to ascertain their greatest thickness. That well gives 226 feet above the pebbles; and I doubt whether this is exceeded in other places.

In the lower beds of these upper sands numerous green grains occur, either in patches or disseminated through the sand, and casts of shells are to be found in several pits and cuttings. I may mention Sandhurst cutting on the South-Western Railway, near Wellington College, Cæsar's Camp, Easthampstead, a road-cutting about a mile from the Royal Military College, on the Windsor Ride, and the cutting through the spur of the Fox Hills (S.W. R.), from which Prof. Prestwich obtained several fossils.

There are two very fine sections in the higher beds—the first at Crawley Hill, near Camberley, and the second at Tunnel Hill, on Pirbright Common.

The Crawley-Hill cutting, on the South-Western Railway, near Camberley Station, is unfortunately overgrown; but casts of shells were formerly very abundant there, though for the most part ill-

*Section on South-Eastern Railway at Wellington College.*  
(Horizontal scale 4 inches to 1 mile. Vertical scale 150 feet to 1 in ch.)



In the above cut the dip of the beds to the north of Wellington-College Station is too high; they are, in fact, nearly horizontal, and are brought into the cutting by the fall of the line, which is here 1 in 154. Pebbles like those in the pebble-beds cover the surface of the ground for some distance north of the station. I have omitted the gravels and surface-earth.

preserved. They are apparently of nearly the same species as those at Pirbright.

At Tunnel Hill, on the Woking-Aldershot branch of the South-Western Railway, the casts are well preserved, and impressions of the exterior of the shells are often to be found.

The section is as follows:—

1. Darkish yellow sand, passing into ochre sand, with casts of shells. 20 ft. 6 in.
2. A line of bright yellow sand. 8 in.
3. White sand, with numerous casts, passing into white sand, with patches of yellow sand, irregular iron-sand layers and concretions, numerous casts and impressions of shells, and a few flint pebbles. 27 ft.
4. Variously tinted sands, with very few casts of shells. 39 ft. exposed.

*Fossils from the Upper-Bagshot Sand, Tunnel-Hill Cutting,  
Pirbright, Surrey.*

- |  |  |
|--|--|
| <p>vc Rostellaria rimosa, Sow.<br/>c Terebellum fusiforme, Lam.<br/>Cancellaria (2 species).<br/>Ancillaria canalifera, Lam.<br/>Voluta, sp. (rare here, but very common at Crawley Hill).<br/>Volvaria acutiuscula, Sow.<br/>c Natica ambulacrum, Sow.<br/>— sp., perhaps N. conoidea, Sow.<br/>c — labellata?, Lam.<br/>c — patula, Lam.<br/>Sigaretus canaliculatus, Sow.<br/>Cerithium sp.?<br/>vc Turritella imbricataria, Lam.<br/>Turritella, or Niso, sp.?<br/>c Littorina sulcata, Pilk.<br/>Solarium bistratum?, Sow.<br/>— plicatum?, Lam.<br/>Phorus (2 species).<br/>Dentalium striatum, Sow.<br/>— (small, smooth species).<br/>Actæon sp.<br/>Bulla attenuata, Sow.<br/>— sp.<br/>vc Ostrea flabellulum, Lam.</p> | <p>vc Pecten reconditus, Sol.<br/>Avicula media, Sow.?<br/>Pectunculus sp.<br/>Nucula similis, Sow.<br/>vc Cardita sulcata, Sol. (variety with tuberculate ribs).<br/>c Crassatella sulcata?, Sol.<br/>vc Lucina mitis, Sow.<br/>c — divaricata, Linn. (Rigaultiana, Desh.).<br/>Diplodonta sp.?<br/>Cardium porulosum, Brand.<br/>c Protocardium parile, Desh.<br/>— turgidum?, Sol.<br/>Cytherea, apparently 4 species.<br/>vc Tellina scalaroides, Lam.<br/>Corbula gallica?, Lam.<br/>c Corbula ficus?, Brand.<br/>c — pisum, Sow.<br/>— striata?, Lam.<br/>Clavagella coronata, Desh.<br/>Serpula extensa, Brand.<br/>— ? sp.<br/>Serpulorbis Marshii.<br/>Two or more species of corals.<br/>Wood.</p> |
|--|--|

*Correlation of the Bagshot Beds with the Hampshire Series.*

A glance at the table of strata (p. 348) will show that there are two beds in which the occurrence of well-preserved fossils gives an opportunity for comparison between the Bagshot and Hampshire series. The first of these is the green-sand bed, E; and the second the higher beds of the Upper Bagshot Sands, marked A in the table. Now, there can, I think, be little doubt that the green sand, E, must be correlated with some part of the Middle Bracklesham of the Hampshire basin; and its great resemblance to the bed numbered



11 in Prestwich's Whitecliff-Bay section leads me to the conclusion that it should be placed in that portion of the Bracklesham termed Group C by the Rev. Osmond Fisher (Quart. Journ. Geol. Soc. vol. xviii. p. 65).

The Bagshot bed resembles Prestwich's bed 11 at Whitecliff Bay in colour and texture, in the abundance of *Cardita planicosta* and large *Turritella*, and in the occurrence of *Nummulites lævigatus*.

Passing now to the upper fossil-bed at Bagshot, marked A, and best seen at Pirbright, I venture to submit that the shells clearly prove it to be of Barton age.

The occurrence of such shells as *Volvaria acutiuscula*, *Littorina sulcata*, *Dentalium striatum*, *Lucina divaricata* (or *Rigaultiana*), *Tellina scalaroides*, and *Clavagella coronata*, all of which are well-marked types and not easily mistaken, taken together with the absence of *Cardita planicosta*, *Pecten corneus*, &c., which are so abundant in the underlying green sand, is, I think, quite sufficient to prove that we are here in Barton beds. On the other hand, if we compare the list of shells from Pirbright Common with that from Long Mead End, Hordwell, published by Mr. Tawney (Proc. Cambr. Phil. Soc. iv. p. 150), we can, I think, feel no doubt that the Long-Mead-End Upper Bagshot Sand, with *Cerithium pleurotomoides*, cannot be correlated with the Upper Bagshot Sand of Bagshot Heath. The upper beds of the Bagshot Sand of Bagshot Heath must therefore be correlated with the Barton beds of Hampshire and the Isle of Wight.

It might be objected to this correlation that it does not account for the absence of the Upper-Bracklesham beds in the London basin; but I think that, in the first place, the distance between the two basins is enough to account for almost any amount of thinning-out or change in the nature of the strata; and in the second place, the clear evidence of a break in the London-basin series, which is furnished by the remarkable pebble-bed marked C in the table of strata, is sufficient to account for the absence of the Upper Bracklesham in that basin.

The only question remaining to be considered is the point at which the division between the Barton and Bracklesham should be placed in the Bagshot area. On the whole, it appears to me to be most convenient to place it at the pebble-bed marked C in the table of strata (this was suggested by the Rev. A. Irving [Proc. Geol. Assoc. iv. pp. 334, 335], and is in accordance with Prof. Prestwich's Goldsworthy section [Q. J. G. S. iii. p. 382]), giving the Barton beds a thickness of 226 feet at least, and the Bracklesham an average thickness of about 45 or 50 feet.

In the Geological Survey Map some of the overlying sands are included in the Bracklesham, on the ground that they contain green grains. This, however, does not appear to me altogether satisfactory, a few green grains being no proof that a bed is not of Barton age; and I think it better to take the pebbles as a division than the very uncertain line proposed by the Survey.

## DISCUSSION.

Prof. PRESTWICH said it was forty years since the opening of a railway-cutting had first given us some idea of the position of these sands. The paper was a very careful record of observations. The fossils were so imperfect that comparison with the representatives of this series in Hampshire was very difficult. He himself had found but few. He thought that the so-called Upper Bagshots of that region were on the whole more probably synchronous with the Bracklesham. The occurrence of a little green sand was not of much importance, except that it sometimes was associated with occurrence of fossils. He asked how many species Mr. Monckton had found.

Mr. J. S. GARDNER said that he thought Mr. Monckton had made a sufficiently large collection to show that the beds were really equivalents of the Barton Beds. As for the lower beds, they were probably freshwater, but might perhaps rather belong to the lower part of the Middle Bagshot than to the Lower Bagshot.

Prof. JUDG thought that the author had brought valuable evidence as to the age of the "Upper Bagshots" of the London basin, showing that they might be correlated with some parts of the Barton series. It was important to have shown that these beds did not agree with the Hordwell Beds or Headon-Hill Sands. There was, indeed, no reason for correlating the two series in the Hampshire and Bagshot areas. For himself he thought it was unsafe to attempt to draw exact parallels between beds sixty miles apart, so far as the minor members were concerned.

Prof. PRESTWICH mentioned that he had found near Cooper's Hill traces of casts of marine shells in Lower Bagshot.

Mr. MONCKTON acknowledged the favourable way in which his paper had been received. He had obtained from the Upper Bagshot 28 species, and from the green-sand bed 18 species. It was easier to enumerate than to name the species.

22. *The AGE of the NEWER GNEISSIC ROCKS of the NORTHERN HIGHLANDS.* By C. CALLAWAY, Esq., D.Sc., M.A., F.G.S. With NOTES on the LITHOLOGY, by Prof. T. G. BONNEY, M.A., F.R.S., Sec. G.S. (Read May 9, 1883.)

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### INTRODUCTION.

IN the summer of 1880 I commenced an investigation into the relations between the fossiliferous limestone of Durness and the great gneissic series which was alleged to overlie it. A portion of my first results I communicated to the Society in a paper\* in which

\* Quart. Journ. Geol. Soc. 1881, p. 239.



I endeavoured to show that the sections at Durness and in Assynt did not display a true ascending series, the limestone in both localities being separated by a fault from the rock which was supposed to conformably succeed it. On the relation of the limestone to the quartzite I formed no opinion; but in the two sections described I found them brought together by faults. As the quartzite passed with apparent conformity below the eastern gneiss on the east of Loch Erriboll, I hinted, in accordance with the views of Murchison, which I had not then seen reason to abandon, that the quartzite might belong to the metamorphic series. From these limited observations I carefully abstained from drawing a general conclusion; and I was convinced that no satisfactory result could be achieved without a detailed survey. Accordingly I devoted a fortnight in 1881, and two months in 1882, to the districts which appeared most promising; and I have now the honour to submit the conclusions to which I have been led.

The published theories on the relation between the Durness limestone and the eastern gneiss are the following:—

1. That the eastern gneiss conformably overlies the limestone, and is of "Lower Silurian" age (Murchison, Geikie, and most authors).

2. That the eastern gneiss is merely the Hebridean brought up east of the limestone along a line of dislocation and inversion (Nicol).

3. That the identity of the limestone of Assynt and Erriboll with that of Durness has not been demonstrated, and therefore that the eastern gneiss, though it conformably overlies the former, has not been proved to be of "Lower Silurian" age (Heddle).

The view which I have here to submit differs from all of the above, but approximates most nearly to that of Nicol. I maintain, with that author, that the junction of the limestone with the eastern gneiss is a line of faulting and inversion; but I shall attempt to prove that this gneiss is a distinct series, newer than, and resting unconformably on, the Hebridean, that Nicol's "igneous rock" overlying the limestone is usually a true gneiss, and that both the older and younger gneissic systems have been brought up over the limestone by great earth-movements. The eastern gneiss I propose provisionally to name the "Caledonian."

## I. THE FORMATIONS CONCERNED IN THE RESULT.

The groups whose relations are to be discussed are the Hebridean or Lewisian, the Caledonian, and the quartzo-dolomitic group which, in view of the doubt which has been cast upon its age by the researches of Prof. Heddle, I propose to call the *Assynt series*.

### a. *Hebridean*.

In addition to the masses usually designated by this name, I include under it a large proportion of the "igneous rocks" of authors. Recently the latter have been described by Dr. Heddle as a new

group, conformably overlying the Dolomite; and he names them "Logan Rock," from Glen Logan or Laggan, where they have been identified by Prof. Bonney as Hebridean. I shall submit evidence to the effect that by faulting, accompanied or followed by powerful lateral thrust, this rock has been thrown over on to the Assynt series to a maximum breadth of about a mile, and along an outcrop of over 15 miles in Sutherland alone. This overlies often produces the appearance of conformity between the Assynt series and the Hebridean.

#### b. *Caledonian.*

This system is divisible into two well-marked groups. The lower I have recognized only in the Erriboll area; and from its clear development in Ben Arnaboll, I have called it the *Arnaboll series* (*b*). It consists of grey, granitoid, very felspathic gneiss, overlain by dark, striped hornblende and mica gneisses, passing up through beds of an intermediate character into the ordinary flaggy gneiss which, from its exposure on Loch Hope and in the lofty peak of Ben Hope (3040 feet), I have designated the *Hope series* (*b*<sub>2</sub>). The latter is very uniform in its lithology wherever I have seen it between Loch Erriboll in the north, and Loch Broom, in Cromartyshire, in the south, and from this line eastwards to Lairg, in Sutherland, and Ben Wyvis, in Ross. It is normally a thin-bedded, highly quartzose gneiss, passing into a felspathic variety on the one hand, and into quartz schist on the other. Within the extensive area described, I have not been able to detect any evidence of the reappearance of the Hebridean. Near Lairg, it is true, the Shiness limestone, which is highly crystalline, is associated with bands of very massive hornblende, together with bands and nests of mica, steatite, and several other minerals, all highly crystalline. From the general relations of these beds, I am disposed to regard them rather as a local variation of the Caledonian, perhaps due in part to the presence of the limestone, than as an upthrust of the Hebridean.

#### c. *Assynt Series.*

1. *Probable Age.*—Two chief objections are urged by Prof. Heddle against identifying the limestone of Assynt and Erriboll with that of Durness.

(1) The absence of the Durness fossils in the Assynt group. Sir R. I. Murchison alleges that "an orthoceratite" was found in quartzite on Loch Erriboll, and "orthoceratites" in the limestone near Inchnadamff. The Erriboll fossil was described by Salter, and compared by him with *Orthoceras* (*Cameroceras*) *Brongniartii* (Troost?). It was given to Murchison by Mr. Clark, of Erriboll House, who fixed its locality. The Assynt fossils were discovered by Peach, and handed to Murchison on the spot. Mr. Peach has recently (1882), in a letter to 'Nature,' positively reaffirmed the genuineness of the discovery. Unfortunately, none of these specimens can be produced. Many observers, including myself, have since diligently searched for fossils in the limestone, but without success.

(2) Difference of chemical composition. Dr. Heddle quotes analyses of the Assynt and Erriboll limestone by Dr. Thomas Anderson, published in the 'Transactions of the Highland Society,' which show that the rock is a "typical dolomite," while the Durness limestone is a "fairly pure" carbonate of lime. I confess myself not fully satisfied with Dr. Heddle's objection. The chemical argument would certainly be of force if it stood alone; but it would have little weight against the merest fragment of fossil proof. The evidence of the orthoceratites is certainly not decisive; but at the same time I hesitate to reject the testimony of such competent observers as Murchison, Peach, and Salter. That the specimen described by Salter was truly an orthoceratite no one who is acquainted with the work of that accomplished palæontologist can reasonably doubt; and that Mr. Clark palmed a deception upon Murchison is not easy of belief, both from the want of motive and from the difficulty of obtaining the specimen.

But, even waiving the fossil testimony just discussed, there are other facts which militate against the Archæan age of the Assynt series. Foremost amongst these I would place the comparatively *unaltered state* of the rocks. The quartzite bears but little upon the point, since we have in the British Islands undoubted quartzites as young as the Llandovery and as old as the Dimetian. But the beds above the quartzite display very slight alteration. In the Brown Flags are shales and slates as unchanged as any of Lower Palæozoic age (Nos. 103, 104, 107, 108, p. 418). In Assynt the Flags contain abundant vegetable impressions, the carbonaceous matter being as distinct and apparently as unaltered as in coal-shales. The unmetamorphosed state of these beds cannot be accounted for on any principle of selective metamorphism. The rocks furnish all the materials for the production of schists. Magnesia is provided by dolomitic flags and limestones. Iron is so abundant that it gives the flags their distinctive colour. Alumina and alkalies are supplied by argillaceous, felspathic, and micaceous constituents. Yet with all the ingredients at hand, not a seam of true metamorphic rock has been formed.

It is not here contended that the absence of metamorphism is absolute disproof of great antiquity; but as all Archæan rocks hitherto studied are more or less metamorphosed, the presumption that an unaltered rock is not Archæan is very strong indeed.

The *abundance of fossil remains* is also unfavourable to the Archæan hypothesis. The upper part of the quartzite is full of the well-known "worm-holes." In the same beds are numerous conical bodies, with a cone-in-cone structure. In transverse section, as they appear on the surface of the beds, the fossils are like three concentric rings, the central one being in diameter about  $\frac{1}{8}$  inch, and the outer ring 1 inch. These peculiarities are hardly such as we should expect in Annelids. Besides the above, there are the "Fucoids" of the Brown Flags. Some of these are described by Nicol as "straight, cylindrical fragments, like stems or branches of trees . . . . Some are marked with obscure scars, as of leaves and



branches. Round or oval markings, like those on the *Stigmara* of the coal, are also not uncommon." This description appears to me strictly correct; and, in addition, I have observed in well-preserved specimens that the stems, which are hollow in the centre, present the appearance of several distinct concentric coats. Whatever this structure may mean, it appears clear that the fossils were true plants, and that they were of by no means the lowest type. I can hardly think but that woody tissue was present in these stems.

*Salterella* (*Serpulites*) *Maccullochii* will complete, so far as I know, the list of fossils. Salter describes these minute forms as "short, subconical, and curved tubes, of thick substance, and with but a slender central perforation;" and he compares them to *Ditrupa*. I have, however, obtained specimens in which a distinct cone-in-cone structure is visible, as in *Piloceras* of the Durness limestone. Transverse sections show the edges of three concentric septa (?), as in Salter's plate\* (fig. 21), and as in the conical fossils described above. These puzzling little things appear to be more like Cephalopods with conical septa than Annelids or Pteropods; but their small size, under 1 inch, suggests a doubt.

As we know of no undisputed fossil remains in undoubted Archæan rocks, the facts just enumerated seem to bear against the Archæan age of the Assynt series. On the whole, I see no sufficient reason to deny the received view of the correlation of this group; but, since a doubt remains, I have preferred to use a local designation.

2. *Subdivisions*.—As I shall have to submit evidence to prove the frequent inversion of the Assynt series, it is of the first importance that we should ascertain the order of its subdivisions in their true position. I must here assume, what I shall hereafter attempt to prove, the non-existence of the so-called "Upper Quartzite" and "Upper Limestone" of Murchison. The chief horizons which I have recognized are the following:—

c<sub>1</sub>. *Torridon Sandstone and Ben More Grit*.—The ordinary Torridon is too well known to need further description; but the variety which I have called "Ben More Grit" requires special notice. A little below the top of Coniveall (3234 feet), the western peak of Ben More, is a band of grit and conglomerate, hitherto grouped with the "Upper Quartzite," of which it forms the base. The lowest beds of this series, as seen in a precipice 600 or 700 feet below the summit in the spur which projects to the south, are greenish conglomerates. The included fragments, which are well rounded, are mainly of quartz and gneiss, the former sometimes reaching a diameter of 6 or 7 inches, and are imbedded in a chloritic matrix. These basement conglomerates pass up into a green grit (No. 94, p. 417), alternating with finer green sediments. Mr. G. H. Bailey, B.Sc., who accompanied me in 1881, descended from the peak by a route which afforded him a clearer section of the higher beds than the line followed by myself in 1882; and he states that he "came upon Torridon, somewhat changed in aspect, after about 300 feet of descent.

\* Quart. Journ. Geol. Soc. 1858, pl. xiii.



It was made up of a series of beds of the usual coarse sandstone with intercalated thin bands of shale, the grit-beds being generally about 6–10 feet, and the shale from 6 inches to 1 foot.” Mr. Bailey estimated the Torridon at about 300 feet. This would make the base of the series about 2600 feet above the sea, which agrees nearly enough with my estimate of 2500 feet, taken by aneroid at a time of considerable atmospheric disturbance. Judging by a large number of blocks of red grit scattered over the gneiss slopes below the conglomerate, there can be no doubt that beds of this rock occur in the precipices above. The grit and conglomerate are continued down the Oykel valley for three or four miles; but the thickness I found not greatly to exceed 100 feet.

The red variety is typically a quartzo-felspathic grit (Nos. 92, 93, p. 417). It occurs abundantly in the localities on the Oykel. It is important to observe that these rocks are truly fragmental. They are composed of material which might have been derived from the Hebridean.

In Ben More the conglomerate and grit rest in horizontal beds upon the nearly vertical gneiss which forms the nucleus of the mountain, and are overlain by the Ben-More quartzite, which I regard as merely a faulted repetition of the quartzite under the Dolomite. It would therefore appear that the grit represents the Torridon sandstone. There are, indeed, slight differences, the Ben-More grit being frequently green in colour, its particles being less often rounded, and its general aspect more strongly suggesting derivation from gneissic rocks. Whether or not this group is exactly contemporaneous with any part of the Torridon is immaterial. It is sufficient for my purpose that it lies above the Hebridean and below the quartzite.

*c<sub>2</sub>. Quartzite.*—This series is tolerably homogeneous from top to bottom; but there are certain differences which render possible a separation into two divisions, a *lower* (*c<sub>2</sub> l.*) and an *upper* (*c<sub>2</sub> u.*).

*Seamy Quartzite, c<sub>2</sub> l.*—The base of the quartzite is characterized by the occurrence of thin seams of shale or grit and bits of red felspar, and, in Assynt, by the intrusion of beds or masses of felsite or diorite. The felspar grains are seen throughout Assynt at this horizon; and the seamy appearance is, so far as I have seen, persistent along the whole line as far as the North Sea. Indeed the uniform character of the quartzite is remarkable. About 10 feet from the base is a thin seam of quartzose grit, which appears at the same horizon at points over 30 miles distant on the strike. The basement of the series in Assynt is often a thin band of conglomerate of quartz in a brownish matrix; and a similar seam occupies the same position on Loch Erriboll. Towards Whitten Head the partings expand, so as sometimes to reach a thickness of several feet.

*Annelidian Quartzite, c<sub>2</sub> u. (Pipe-rock).*—The abundance of vertical burrows has been noticed by most writers. I have been unable to detect them in the lower series; but they characterize the upper part wherever I have studied the group—that is, from Loch Broom to Loch More, a distance of 35 miles, and on Loch Erriboll, 55 miles

from Loch Broom. To these facts I have been able to discover no exception in sections in which the rocks were undoubtedly uninverted. Throughout this paper I avoid the use of the terms "Lower" and "Upper" in reference to the quartzite, in order to prevent any confusion which might arise from the Murchisonian meaning of the words.

I have seen no reason to believe that the quartzite ever largely exceeds 300 feet. The seemingly great thickening in certain localities is, in my opinion, due to repetition by folding or faulting.

c<sub>3</sub>. *Brown Flags (Fucoid beds)*.—The rocks of this zone are very varied. The predominant type is a fine-grained arenaceous flag, which is sometimes argillaceous and sometimes dolomitic. There are also soft, thin-bedded, argillaceous shales, dark slates, and thin beds of dolomite and quartzite. The series, whatever its composition, is distinguished by the abundance of iron, which, by its peroxidation on weathered surfaces, gives rise to the characteristic rusty-brown colour.

I have found this band persistent from Loch Broom to near Whitten Head. On Loch Broom the thickness is about 30 feet; but in Assynt it has expanded to 100 feet, retaining about the same thickness, or rather less, on Loch Erriboll. In the last locality it becomes more arenaceous, its upper beds passing into a kind of imperfect quartzite, in which siliceous seams, weathering out sharply from vertical surfaces, alternate with softer material. This variety graduates upwards into the next band.

c<sub>4</sub>. *Salterella-Grit\* and Quartzite*.—This zone is distinguished by the abundance of specimens of *Salterella Maccullochii*. On Loch Erriboll, where alone the fossils have been found, the beds are about 15 feet thick. Some of the strata are an iron-stained quartzose grit; but quartzite proper also occurs. The *Salterella* abounds in both kinds of rock, but is in better preservation in the grit. In Assynt 10 feet of quartzite holds a corresponding position between the flags and the dolomite; and on Loch Broom the quartzite has considerably expanded, the flags being much thinner; so that the aggregate thickness of flags and *Salterella*-quartzite is about the same as in Assynt.

c<sub>5</sub>. *Dolomite*.—Two years ago, before any doubt of the identity of the Durness and Erriboll limestones had been expressed, I was struck with the fact that the latter was but slightly susceptible to the action of hydrochloric acid; so that I was quite prepared for Dr. Heddle's announcement of their chemical difference. I have recently applied the acid test to sixteen specimens, taken from widely separated localities between Ullapool and Erriboll. Fifteen of them exhibit but very slight effervescence, except along joints, where decomposition may be supposed to have supervened. The sixteenth, from Loch Broom, where it was in contact with Hebridean gneiss, effervesces more freely. But in this case chemical reactions have

\* Since this paper was written, an article has appeared in the 'Geological Magazine,' by Prof. Lapworth, F.G.S., in which the same name is proposed for this zone.

apparently taken place. The gneiss is chloritic, its silica having probably taken up a part of the magnesia of the dolomite; and the dolomite, thus partially decomposed, displays imperfectly the reaction of calcic carbonate.

On the other hand, the Durness limestone, so far as I have seen, always effervesces freely with acids.

The chemical distinction between the Durness and Erriboll limestones, pointed out by Dr. Anderson and reasserted by Prof. Heddle, thus appears to me to be firmly established.

In Assynt I observed that the lower half of the Dolomite was of a dark grey colour, sometimes weathering almost black, while the upper part was nearly white. The same difference is equally well marked on Loch Erriboll. This separation into a *Lower* (c. l.) and an *Upper* (c. u.) *Dolomite* is useful as an aid in determining whether or not inversion has taken place.

The maximum thickness of the dolomite is about 300 feet, or rather less. This estimate does not materially vary anywhere on the line of strike between Ullapool and Erriboll, the local changes being due, I believe, not to thinning but to faulting.

## II. THE RELATIONS BETWEEN THESE FORMATIONS.

I describe the districts examined from S. to N., since the evidence I have to adduce grows progressively stronger in that direction.

### LOCH BROOM.

As this is one of the districts in which "a gradually descending series" has been affirmed, I devoted to it in 1881 a very close examination. If there is no break here, we ought to find the same succession wherever we run our sections; for, within so limited an area, variations of thickness along the strike cannot be considerable; and it is of course impossible that this cause, though it may account for the absence of a group, should interfere with the true order. Of the sections examined I will describe six. These I take from S. to N.

#### 1. *Section along the shore of the Loch from Ullapool to the S.S.E.*

At about half a mile from the hotel we come to sandstone and conglomerate, which occupy the shore for a considerable distance; but in the rounded promontory which terminates in Corry Point a gneissic rock suddenly comes in. This is the "serpentine or felspar porphyry" of Nicol; but in the paper of Sir R. I. Murchison and Prof. Geikie\* it is described as "serpentinous and felspathic rock containing pebbles of jasper," and it is regarded as "a highly metamorphosed band of felspathic grit." It is the "Logan Rock" of Dr. Heddle. As it plays a very important part in our inquiry, it is necessary to examine its true nature very carefully.

I first made the acquaintance of the "Logan Rock" on the high ground about half a mile due east of the hotel. It was a greyish

\* Quart. Journ. Geol. Soc. 1861, p. 185.



aggregate of felspar and quartz, without foliation; and, not suspecting any thing wrong, I took it to be "porphyry," though there was something about it which suggested the granitoidite with which I was familiar in Wales and Shropshire. Soon after I found distinct foliation, dark crystalline bands striking to the north-west. This was puzzling; but as, at a short distance off, the rock was seen clearly to overlie the dolomite, I clung to the "igneous" theory. Coming down to the present section new light began to dawn.

This formation occupies the shore of the loch for about a quarter of a mile, filling in the entire break between the sandstone and the Caledonian, no trace of quartzite or dolomite being visible, though bare rock is exposed almost the whole distance. The Caledonian crops up on the flat beach in contorted beds, dipping on the whole easterly, and ending abruptly on the west. Fifty yards from it we come to a green felspathic rock, without definite structure, but looking like partially decomposed gneiss. This passes towards the north-west into a true gneiss (No. 74, p. 416), composed mainly of reddish felspar, quartz, and a greenish mineral, the folia either dipping E.N.E. at a low angle, or rising nearly to the vertical, and striking to N.N.E. The resemblance of this gneiss to some of the Malvern and Wrekin types was very marked. Its appearance is widely contrasted with that of the Caledonian. The foliation is more massive; the crystallization is much coarser; the rock is quite destitute of that fissile structure which causes ordinary Caledonian to split up into flaggy pieces, and it is much tougher under the hammer. Its structure and behaviour was altogether that of the Hebridean, to which I referred it; and the opinion then formed has been confirmed by a long study of the rock in more northerly localities during two successive summers, as will hereafter appear.

Continuing along the shore to the N.N.W., we pass abruptly from the gneiss to the conglomerate. By Murchison and Geikie it is stated that there is a gradual transition from the one into the other; and hence it is inferred that the gneissic rock is a "metamorphosed band of felspathic grit." The section described by these authors is undoubtedly the one studied by me; but, after careful examination, I could not detect the slightest evidence of a gradation. The line of junction is perfectly sharp. The gneiss (No. 63, p. 416), which mainly consists of felspar and a little quartz, and is coloured green (apparently by chloritic products of decomposition, as is commonly the case at faulted junctions), is in actual contact with conglomerate and grit. The gneiss and the conglomerate are plastered together by the chloritic mineral, but are readily separable by a slight blow of the hammer. The plane of junction, which displays slickensides, is nearly vertical, the gneiss slightly overhanging the conglomerate. The bedding in both rocks is very obscure.

In the same locality, a little way up the slope, the gneiss rests on quartzite; and close by the conglomerate rests on quartzite. My interpretation of these facts is, that by faulting, supplemented by lateral squeeze, older deposits, Hebridean and Torridon, are brought up and thrown over onto the quartzite.



## 2. Section along the road from Ullapool to the S.E.

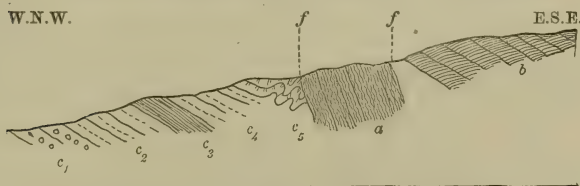
Near the hotel the Torridon is succeeded by the Quartzite, dipping E.N.E. at  $15^\circ$  and conformably overlain by Brown Flags and the quartzite which holds the place of the *Salterella*-zone. At the bridge and fall, red sandstone, undistinguishable from the Torridon, suddenly comes in; and close by is a small exposure of dolomite, with a dip of  $10-15^\circ$  to E.N.E. As the place of the latter is on the high ground, 200 or 300 feet above, there must here be both a faulting-up of the Torridon and a faulting-down of the dolomite. Torridon then reappears, overhanging the road for some distance, and is overlain by quartzite, the relations between the two being obscure, owing to the absence of clear bedding. The quartzite is apparently overlain by the Caledonian.

This section differs materially from the preceding, though they are drawn along lines which diverge from each other not more than 200 or 300 yards at the maximum. The level of the present section, however, is about 100 feet higher. The Hebridean, though conspicuous on the shore close at hand, does not appear; and there are no signs of the inversion of the Torridon on the Quartzite. The Dolomite (which, on the received hypothesis, should intervene between the Quartzite and the Caledonian) is also wanting in its proper place.

## 3. Section from Ullapool to the E.S.E. (fig. 1).

This section starts from the same point as the last, but keeps the top of the slope above the road. Passing over the Torridon, Quartzite, Brown Flags, and *Salterella*-quartzite, we come to the Dolomite, which rises in dip, and to the east is suddenly contorted for a breadth of about twenty yards into a regular series of sharp folds, having evidently been crumpled up against the Hebridean, which appears near at hand. Beyond the Hebridean we soon reach grey thin-bedded gneiss (Caledonian) with undulating and undecided dips.

Fig. 1.—Section from Ullapool to the E.S.E.



For explanation of the letters ( $c$  &  $c$ .) see Synopsis of formations, p. 355.

$ff$ . Faults.

Following the Dolomite and Hebridean respectively along the strike to the N.N.W., the broken nature of the ground becomes very evident. The Dolomite every now and then suddenly disappears,

and the old gneiss is brought against the Quartzite. Limestone is not a rock which thins out from 100 feet to nothing within 50 yards, and then as abruptly reappears. Dislocation, not deposition, can account for such facts. But walking over the zone between the Quartzite and the Caledonian, the proof of dislocation is absolutely convincing. The ground is literally a pavement of fragments. Blocks of quartzite, dolomite, and Hebridean are fitted in together without any principle of arrangement. In one spot, for example, passing along the strike of the Hebridean, we come to dolomite, then on to Hebridean, and then to quartzite.

In this locality some soft shale occurs in association with the quartzite; and in one place the shale is in actual contact with Hebridean. If what I have called "Hebridean" is igneous, why was not this shale altered? Or if this Hebridean is a part of the "Lower Silurian" subsequently metamorphosed, why should the metamorphosing agent have acted upon grit, and left shale in contact with the grit unaffected?

#### 4. *Section from Ullapool over the high ground to the E.N.E.*

This section was drawn with special care, the heights being taken with the aneroid. The base of the Quartzite was reached at 210 feet above the sea, and the Caledonian at 700. The Assynt series was unbroken up to the *Salterella*-quartzite (660 feet), which suddenly rose from its normal dip of  $15^{\circ}$  to  $45^{\circ}$ , and was succeeded by the Hebridean, which here is a reddish granitoidite. The dip of the Assynt rock is to the E.N.E. Beyond the old gneiss the Caledonian (Hope series) is seen dipping to the E.S.E. at  $10^{\circ}$ . The abrupt plunging-down of the *Salterella*-quartzite would suggest a fault, even were there no other evidence to show that the Dolomite has been entirely thrown out. It is also to be noted that the strike of the Caledonian diverges from that of the Assynt group by  $45^{\circ}$ .

#### 5. *Section along the south side of the Ullapool river, W. to E.*

This line runs about a mile north of the last. Walking up the valley, we first notice a fault in the Quartzite, the Torridon being thrown up to the east. Then we have the succession of the Assynt series nearly complete, the Dolomite approaching its maximum thickness of 300 feet. The upper part is probably cut out; for, above the narrow gorge which the river has excavated in this rock, the Dolomite is abruptly succeeded by the Torridon, again faulted up, the junction being very well defined. Along the line of contact deep trenches are hollowed out. Beyond the Torridon we come to the granitoid gneiss (Hebridean); and at the west end of Loch Auchall we reach the Caledonian.

#### 6. *Section along the north side of the Ullapool river, W. to E.*

The succession in the lower part is similar to the last, the fault in the Quartzite being very clearly seen. But further east there is a remarkable difference. Though the two sections are parallel at a distance of little over a quarter of a mile, both the Dolomite and

the Hebridean are wanting, the Torridon occupying the entire breadth of country between the Brown Flags and the Caledonian. The fault, which is in the flags, is perfectly clear. The rocks are broken into a chaos of fragments—pieces of shale, dolomite, flags, and quartzite being thrown together in inextricable confusion. On the east side the Torridon rises in a small overhanging cliff.

The relations between the sections described are seen in the following table. The numbers 1–6 stand for the sections. Up to the flags the order is the same in all; but between the flags and the Caledonian the six sections present *six different successions*. Which of these is to be selected as the “clear ascending series”? The sections are too close together to permit of thinning-out, even if there were no signs of dislocation. If we reject dislocation, we have to invent new formations at random, substituting imagination for the known principles of science.

*Table showing the Variations in the Ullapool sections.*

	(1. (Obscure.)			Tor.		Heb.	
Torridon, Quartzite, Brown flags.	2. S. Q.	Tor.	Dol.	Tor.	Quartzite.	.....	} Caledonian.
	3. S. Q.	...	Dol.	.....	.....	Heb.	
	4. S. Q.	...	.....	.....	.....	Heb.	
	5. S. Q.	...	Dol.	Tor.	.....	Heb.	
	6. ....	...	.....	Tor.	.....	.....	

S.Q. = *Salterella*-quartzite. Tor. = Torridon Sandstone. Dol. = Dolomite.  
Heb. = Hebridean.

A very simple hypothesis will render intelligible the facts enumerated. The zone between the Quartzite and the Caledonian is sliced by several subparallel faults, which increase in throw from west to east—that is, towards the junction with the Caledonian. On the line of the Ullapool river, Torridon is first brought up through the Quartzite, and further east through the Brown Flags or the Dolomite, while still nearer the Caledonian the Hebridean is faulted up. On Loch Broom and in the hills above, the facts are similar, though the graduation in the throws is not quite so distinct. We shall find the same law in operation in Assynt with still more striking results.

These conclusions are mainly negative. They show that in the Ullapool area there is no evidence of a continuous series. At the same time they dimly suggest the clear proof of inversion to be described in future sections.

#### ASSYNT.

Before we can reach a conclusion on the main issue, it will be necessary to settle several preliminaries. Of these the most important are the true nature of the “Upper Quartzite,” the “Logan Rock,” and the “Upper Limestone.”

#### A. *The “Upper Quartzite” non-existent.*

Sir R. I. Murchison inferred the existence of an upper band of quartzite from sections at two localities, Croc-an-drein and the Bal-

loch under Coniveall. Two years ago I submitted to the Society reasons for believing that the limestone at Inchnadamff was the highest rock in the district; and I showed that, when followed to the south-east, it was seen to dip away from the so-called "Upper" Quartzite, and to form the north-eastern side of the Stronchrubie basin. Having minutely resurveyed the ground, I beg to offer what appears to me absolutely conclusive proof of my original view.

The western slopes of Cnoc-an-drein extend between the Burn of Calda and the parallel stream called Poulan-drein, a breadth of over a mile. The junction between the Dolomite and the "Upper" Quartzite is more or less clearly exposed in the escarpment between the two burns, and more distinctly in the burns themselves.

*Section on the Burn of Calda.*

Leaving the high road a little north of Inchnadamff, and ascending the slope towards the col between Cnoc-an-drein and Glasven, we first detect small faults in the Dolomite; and a little higher up the throw increases, the Brown Flags, much squeezed and contorted, re-appearing east of the Dolomite and being followed by a repetition of the Dolomite in regular sequence. Beyond this, the evidence at first sight appears to favour the old view. In Calda Burn, at a water-

Fig. 2.—*Section on the Burn of Calda.* (Scale 5 inches to 1 mile.)



fall, the Dolomite, somewhat contorted, is seen to be succeeded and seemingly overlain by quartzite. Two facts, however, at once suggest suspicion of this apparent conformity. Ascending the stream, we find the quartzite dipping regularly to the E.N.E. for nearly a quarter of a mile; but suddenly the dip rises and the rock is bent back into a large overthrown fold (fig. 2). This contortion is clearly seen on both sides of the burn, which here forms a cataract, whose bed is in part formed by the curved surface of the strata. The quartzite is overthrown about  $20^\circ$ , the strata dipping into the hill at  $70^\circ$ . Again, in a small tributary of the burn, close to the junction of quartzite and dolomite, is a fragment of a bed of dolomite 18 inches thick, evidently not far from its matrix. This block is bent in the middle into a small overthrown fold, as clearly as could be represented in a diagram. Now the large overthrow in the quartzite higher up proves the operation of an enormous lateral force; and the contorted dolomite shows that the same pressure was at work at the junction. Taking these facts in conjunction with the graduated faults before described, there appears no improbability in the suggestion that the



Dolomite may be brought into contact with or even under the Quartzite by a reversed fault.

Towards the top of the burn, about 200 yards above the overthrown fold, the quartzite curves up to the N.E., *dipping away from* the gneissic ridge of Glasven; and examining its base, we find an abundance of red felspar bits, just as at the base of the quartzite on Loch Assynt. This quartzite is also penetrated by felsite, apparently in the bedding, as is commonly the case with the admitted "Lower" Quartzite of this district.

### *Scarp between Calda Burn and Poulan-drein.*

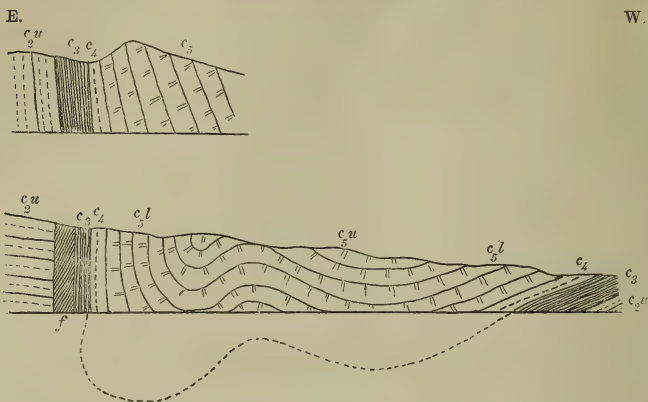
Returning to the junction of dolomite and quartzite, we trace it along the escarpment to the south-east for about three quarters of a mile, and there is little to be seen which could suggest a fault; but the outcrop is along the strike, and there is no visible superposition of quartzite on dolomite. But 200 or 300 yards from Poulan-drein, the actual contact of the two rocks is seen in a large pot-hole, 30 feet deep, and forming a gash running east and west. Its northern side is a face of quartzite vertical right down to the base. The bedding is sharply bent up to the south-west. The south side is occupied mainly by the dolomite, lying nearly horizontal, and coming almost into contact with the quartzite at each end of the fissure, both rocks being very much broken. Igneous rock is intruded into the quartzite, and along the bottom of the hole. As this fissure is only a few yards wide, it is obvious that, if the dolomite and quartzite are conformable, the former should be seen in the lower part of the quartzite cliff. The evidence of faulting here seems to be nearly conclusive.

Between the pot-hole and Poulan-drein, the exposures become scanty; but it is seen that the Dolomite retains its strike, while the strike of the Quartzite turns round through almost a right angle, the strata dipping gently to the S.E. right down to Poulan-drein.

### *Section on Poulan-drein (fig. 3).*

The rocks up the stream are clearly exposed; and the evidence they furnish is decisive. Ascending from the shore of the loch, we pass over Quartzite, Brown Flags, *Salterella*-quartzite, and Dark Dolomite, all dipping steadily at about  $15^{\circ}$  to E.N.E. The White Dolomite succeeds, forming a shallow syncline, as seen on the south-east side, about 100 yards from the stream. Beyond this the Dark Dolomite reappears, but with reversed dip, *i. e.* to the W.S.W., and, after two or three rapid undulations, is sharply bent up, at the foot-bridge standing nearly vertical, and becoming absolutely so a few yards higher. At a little fall, 50 yards above the bridge, the dolomite is conformably underlain by a band of quartzite 10 feet thick, holding the place of the *Salterella*-zone. This quartzite forms the fall. Above it we come immediately to the Brown Flags, 100 feet in thickness, in vertical beds, but in places actually bent back so as to dip at  $80-85^{\circ}$  into the ridge. The section in the burn above is obscure for some distance; but in a small cascade which falls down

Fig. 3.—Section on Poulan-drein. (Scale 3 inches to 1 mile.)



the right bank the uncertainty is removed. The Brown Flags, in curved overthrown beds, are succeeded, after an interval of a few yards occupied by drift and fragments, by the quartzite which we traced along the scarp, *dipping to the S.E. at 5°*. This quartzite is full of the "worm-holes;" and similar rock can be traced up Poulan-drein for over a mile, and over the south-eastern slopes of Cnoc-andrein to the very summit (over 1500 feet).

Prof. Miall, F.G.S., Mr. Tiddeman, F.G.S., and Mr. Eccles, F.G.S., visited this section under my guidance; and they all agreed that there was an overthrown syncline, with a fault beyond; but they were not sufficiently familiar with the district to express an opinion on the age of the quartzite east of the fault.

In this section we see that the Assynt group forms a synclinal fold thrown back upon itself; while quartzite, perfectly resembling the Annelidian Quartzite on the west side of the syncline, appears to the east in nearly horizontal beds. The natural interpretation of these facts is, that the underlying quartzite has been brought up along a line of dislocation and crush, and pushed laterally to the west, bending back the dolomite and flags. The upthrow cannot be great, the place of the Annelidian Quartzite being immediately under the Flags.

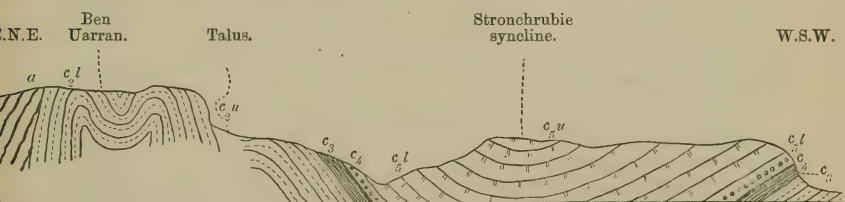
*Quartzite of Cnoc-an-drein.*—I have said that the Annelidian Quartzite at the Poulan-drein fault can be traced without a break to the summit of this mountain. Going down from the summit over the north-western scarps towards Calda Burn, we pass over a descending series, till at the burn we reach the quartzite with red felspar bits. But this quartzite may be traced down the burn till it seems to overlie the Dolomite, as in the section described. In other words, on Calda Burn the Dolomite is conformably (!) succeeded by beds which are from 100 to 200 feet lower in the quartzite series than the strata which conformably (!) overlie the Dolomite in Poulan-drein!

"*Logan Rock*" of *Glasven*.—It is necessary here to anticipate a part of our proposed discussion on this disputed rock. In the upper part of *Calda Burn* the Quartzite rests upon gneiss. This rock is massive and coarsely crystalline. Were there no theoretical reasons to suggest a contrary conclusion, I think it would occur to no one acquainted with the district that this was any thing but the ordinary Hebridean, which appears in place a mile and a half to the west. Many hand-specimens taken at random from both localities are quite undistinguishable. With the exception of a thin capping of quartzite, this gneiss forms the chief mass of *Glasven* (2541 feet). The bedding is much contorted, but is, on the whole, towards the east. According to the received view, this gneiss is conformably intercalated between the Dolomite and the "Upper" Quartzite. But in our former section (fig. 2, p. 368), the quartzite is alleged to rest, and does appear to rest, upon the dolomite. We are therefore asked to believe that this great mass of gneiss has thinned out within 500 yards. Other difficulties will be pointed out further on.

*Section from the west end of Ben Uarran to the high road south of Inchnadamff (fig. 4).*

This line runs parallel to *Poulan-drein*, at a distance of about 400 yards. Standing at the fall over the *Salterella*-quartzite in *Poulan-drein*, and looking along the strike to the south-east, we can see the Dolomite (upper section in fig. 3) rising up into the low ridge behind the house called in the Ordnance Map *Glenbain*, and the beds can be traced without a break between the two points, and on continuously to the S.E., dipping steadily to the S.W., and forming the N.E. side of the *Stronchrubie* syncline. At *Glenbain* the Dolomite is regularly

Fig. 4.—Section between the west end of *Ben Uarran* and the high road south of *Loch Inchnadamff*. (Scale 3 inches to 1 mile.)



underlain by the Brown Flags, just as on *Poulan-drein*, but with a lower dip; and to the south-east the *Annelidian* Quartzite comes in conformably under the flags. Turning to the N.E., and ascending the slopes of *Ben Uarran*, we pass outcrops of the same quartzite. Then we find it roll over slightly to the N.E. and after a narrow interval occupied by talus, we come again upon the *Annelidian* Quartzite almost vertical. It is impossible to speak with certainty of what underlies the talus; but it may mask the prolongation of the *Poulan-drein*

fault. As rocks of the same zone occupy the ground on both sides, there can be but little throw, even less than on Poulan-drein. Indeed this fault can be little more than a crack caused by the syncline being compressed to fracture. Higher up the quartzite is underlain by rocks of the seamy type, with felspar bits and intrusions of felsite and diorite. Reaching the summit of the western spur (1800 feet) of the mountain, we find these beds squeezed up against a mass of gneiss into several very closely appressed folds.

Returning to Glenbain, we start, in the opposite direction, to the south-west. The Dark Dolomite, dipping S.W., is followed by the white Dolomite, which lies in a syncline, on the S.W. side of which reappear in regular succession all the members of the Assynt series. The outcrop of the higher subdivisions forms the precipice overhanging the high road between Stronchrubie and Inchnadamff, the Quartzite and Torridon rising into the well-known mountain-masses south of Loch Assynt.

We have in this important section an indubitable syncline, the northern side of which has been thrust laterally by the mass of gneiss, so that the dip is higher, and the rock is sharply contorted. The section is unbroken, except at the narrow interval, a few yards wide, occupied by talus; but the Annelidian Quartzite occurring on both sides of it, there is no reasonable doubt of the completeness of the series in both halves of the syncline. If this reading is correct, we must admit that the "Lower" Quartzite of Canisp, after passing under the basin of dolomite, is transformed into the "Upper" Quartzite of Ben Uarran!

I may be permitted to revert to an argument adduced in a previous paper\*, and which a more detailed study of the ground brought home to me with irresistible force. What has happened to the northern side of the Stronchrubie basin in its prolongation to the west? Near Glenbain the series is complete down to the Annelidian Quartzite; but west of Poulan-drein, a distance of from 500 to 600 yards, the whole has vanished. What has become of it, if it is not faulted out? And if it is faulted out, the argument for an "Upper" Quartzite, so far as Murchison's celebrated Cnoc-an-drein section is concerned, falls to the ground.

*Section in the Balloch under Coniveall (fig. 6, p. 383).*

This is the second locality where the Dolomite is alleged to pass below an "Upper" Quartzite. I may freely admit that an observer who had not studied the district in detail might naturally form Murchison's opinion. On the west side of the pass we see clearly exposed the typical series from the Quartzite, full of "worm-holes," to the Dolomite, the whole dipping E.N.E. at 40°. At the south end of the gap the Dolomite appears to dip below quartzite.

That there is an unbroken succession here is refuted by the following considerations:—

(1) The White Dolomite and the greater part of the Dark Dolomite are absent, the thickness of dolomite being very slight. The

\* Quart. Journ. Geol. Soc. 1881, vol. xxxvii. p. 243.



Dolomite series is complete about a mile to the west, at Loch Mao-lack Corry; and it is also seen in both its members on Loch Erri-boll, at 25 miles distance. It is therefore highly improbable that such a rapid attenuation should occur between Loch Maolack and the Balloch.

(2) The dolomite at its junction with the "Upper" Quartzite is crushed into an angular breccia for a distance of several feet, a fact the significance of which it is needless to point out.

(3) The quartzite which it is alleged to overlies contains bits of red felspar, as in ordinary basement quartzite.

(4) If there is no fault here, *several hundreds, if not thousands, of feet of gneiss have entirely thinned out within 100 yards.* On the precipitous slopes just above the dolomite to the east, we come to massive gneiss (Logan Rock) rising in steep cliffs to about 1000 feet above the Balloch (1500 feet), extending to the east in the tremendous precipices which fall down from the peaks of Ben More, and, in fact, forming the chief mass of that magnificent group of mountains. As the bedding is vertical or very high, the thickness must be considerable. *Ex hypothesi* the place of this gneiss is between the Dolomite and the "Upper" Quartzite; yet, within a stone's throw to the west, the gneiss is wanting! Comment on such a fact is superfluous. My full reading of this section, with an illustration (fig. 6), will be hereafter given (p. 383).

#### *Section up Glen Coul (fig. 7, p. 391).*

I have shown that in the typical localities of Murchison the so-called "Upper" Quartzite is composed of two members, "Seamy" and "Annelidian," which precisely resemble the two divisions of the "Lower" Quartzite. But it will possibly be urged that this similarity is due to a repetition of similar conditions. This objection, however, could hardly be made if in any place we found the "Upper" Quartzite to include the chief members of the Assynt series. Such a section actually occurs in Glen Coul.

About a mile up the glen, we see that the "Logan Rock" is overlain by quartzite, seamy, with red felspar bits. Leaving the stream and ascending the slope to the north, we come to the Annelidian Quartzite; and just below the conspicuous peak formed by the Caledonian, the Brown Flags occur in place, overlain by dolomite. The quartzite is rather below its average thickness. The flags also are attenuated; but we can detect two varieties of the group, shales and ferruginous dolomite, such as are seen at the mouth of the glen, *below* the Hebridean. The dolomite is very thin, probably under 20 feet. It is of the typical dark-grey type. The total thickness of the Assynt rocks in this section I estimate at a little under 250 feet. On the sea-loch, over a mile to the west, it may reach 100 feet more; but even here the Dolomite is, in some spots, very thin or entirely wanting. The only difference between the groups above and below the Hebridean is, that in the western section the Flags and sometimes the Dolomite are much thicker. But that

the Assynt series should thin out towards the east is what might be expected from the well-known behaviour of its lowest member, the Torridon Sandstone. As regards the Dolomite, its frequent thinness or absence is, I believe, due rather to faulting than deposit-conditions.

Dolomite of the dark-grey type is also seen a little above Annelidian Quartzite near Rhie Cnoc, a mile or so south of Glen Coul. I did not detect the Flags on a hasty inspection; but if present, they could not be of average thickness.

Those who deny that the section in Glen Coul is merely the ordinary Assynt group repeated to the east, must believe that, after an interval represented by the "Logan Rock," the operations of nature reproduced an almost exact facsimile of the "Lower" series—viz. seamy quartzite with red felspar bits, annelidian quartzite, brown flags, including two well-marked types, and dark dolomite. I may safely assert that the science of geology has not hitherto furnished us with an example of such a coincidence.

#### B. *The "Logan Rock" not separable from the Hebridean.*

This remarkable group attains considerable dimensions in Assynt. Commencing in the south, we find it forming the mountain Scounan (2028 feet). Then crossing the valley of the Oykel, it rises into the Eagle Rock (2345 feet) (No. 76, p. 415); and it is continued to the north in the Ben More group, constituting the whole of that extensive mass, except a capping of grit and quartzite. It is enveloped in quartzite in Ben Uarran; but it reemerges at the western end; and being again covered in by the quartzite of Cnoc-an-drein, it ascends to over 2000 feet in Glasven. From this point it is continued to the north, in elevations of from 1500 to 1700 feet, across Lochs Glen Coul and Glen Dhu to Craig Dhu (No. 80, p. 416) on Loch More. To the east of Glasven, it is represented in Dr. Heddle's map as forming the main part of Ben Uie (Uidhe) and the hills above Gorm Loch.

This rock, whatever its age, is as much a gneiss as the Hebridean. There is the same massive bedding, the same coarse crystallization, the same toughness under the hammer, the same non-fissile fracture, the presence of similar nodular masses of greenish hornblende, the same abundance of epidosite\*, and the prevalence of the same essential minerals, quartz, felspar, and hornblende or mica. Such differences as occur are merely varietal. "Logan Rock" within a mile of Hebridean differs no more from it than do varieties of Hebridean at the same distance from each other.

#### a. *Objections to the Hebridean age of the "Logan Rock" considered.*

Dr. Heddle, comparing the lithology of the two rocks, affirms that accessory minerals are present in the Hebridean, but wanting

\* Admitted by Prof. Heddle, according to Mr. Hudleston (Geol. Mag. Sept. 1882, p. 396).

in the "Logan Rock." The epidosite and the nodules of hornblende are surely exceptions to this. Assuming, however, the general accuracy of Dr. Heddle's generalization, I may observe as follows:—

(1) That the occurrence of accessory minerals in some parts of a formation does not prove that they will be found throughout its entire extent. The Caledonian, for example, usually contains few minerals, but at Shiness they are found in rich abundance.

(2) That the western area is in some places penetrated by granite veins. May not these have had something to do with the accessory minerals? Indeed, most of the minerals identified by Dr. Heddle are referred by him to the Cape Wrath-Durness district, in which granite veins abound, and some of the minerals are stated to occur in intrusive dykes, a fact which I myself observed near Durness.

(3) That the area occupied by the "Logan Rock" is insignificant compared with the large tract of Hebridean; and, from what I have seen of the old gneiss, I more than suspect that many areas of undoubted Hebridean could be found in which minerals are as scarce as in the "Logan Rock." The only minerals (omitting the epidosite and hornblende nodules) I have detected away from Durness are some nests of brown garnet, found above Kyle Sku ferry.

While, therefore, conceding that Dr. Heddle's objection deserves consideration, I cannot admit that it is at all decisive of the question. General characters are of much more value than local peculiarities; and in this case the general resemblances are clear and decided.

The comparative absence in the "Logan Rock" of planes of separation between beds has been adduced as another mark of difference. Here, however, I dispute the alleged fact entirely. Although familiar with both rocks, I have been unable to detect any marked distinction between them in this respect.

(4) A difference of weathering has also been asserted. The Hebridean is said to be more thickly clothed with vegetation than the "Logan," owing, presumably, to the formation of more soil. But I believe this is due merely to a difference of level. The "Logan" generally forms much higher ground, and has been more widely cleared of its Boulder-clay. At low levels it is as green as the Hebridean. On the other hand, on lofty ground, as on the higher slopes of Ben Stack, the Hebridean has the bare "knobby" appearance of the "Logan Rock."

b. *The Author's Objections to the Contemporaneity of the "Logan Rock" with the Assynt Series.*

It is granted at starting that the "Logan Rock" does actually overlies some part of the Assynt group; but the contention is that this position is due, not to deposit, but to dislocation.

1. *The "Logan Rock" not conformable to the rocks below it.*—I have already shown that at Ullapool the massive gneiss rests at different points upon each of the members of the Assynt series,



from the Torridon to the Dolomite. A similar discordance is seen in Assynt. In Scounan and Ben More it lies upon Ben More Grit (Torridon), upon the Quartzite in Ben Uarran and on Camaloch, and upon the *Salterella*-quartzite on the south side of Loch Glen Coul. At the head of Loch Glen Coul it rests indiscriminately on quartzite, brown flags, and dolomite.

Besides this, there is a frequent want of concordance in the strike of the "Logan" and of the rock under it. Thus, on Loch Glen Coul the normal direction of the Assynt series is to N.N.E., while the strike of the gneiss which lies over it in the steep cliffs is almost invariably to some point between W. and N.W. At the actual contact there is sometimes conformity of dip, due, as I believe, to the enormous pressure to which the rocks were subjected during the overthrow; but these coincidences are merely local.

On Loch Glen Dhu, further north, the gneiss strikes E. and W., the Assynt rocks maintaining their N.N.E. direction.

2. *The "Logan Rock" not conformable to the rocks above it.*—It is impossible for two groups to exhibit a more marked unconformity than exists between the "Logan" and the "Upper" Quartzite of Ben More (fig. 6, p. 383). The gneiss is magnificently exposed in the precipices which encircle the wild tarn of Dhuloch More. The strike is usually to the N.N.E., in massive, almost vertical, sometimes intensely contorted beds. The overlying grit and quartzite are either horizontal or dip in an easterly direction at a low angle. In the section on the south side of Coniveall, already described in part (p. 372), the conglomerate and grit are horizontal, and the gneiss is almost vertical.

Ben Uarran is capped by nearly horizontal quartzite, while the gneiss which appears at the west end has a high dip to E.N.E.

The discordance is also seen at the north end of the summit of Glasven, above Corry Dearg. The "Logan Rock" is sharply bent into a syncline, into which the quartzite has sunk; and, apparently by a continuation of the lateral pressure, the quartzite is squeezed into two or three overthrown folds combined with reversed faults. These contorted beds are seen as in a vast diagram in the cliff facing to the north, overhanging the loch. On the plateau above, the continuation of these beds lies almost horizontally upon the high-dipping gneiss.

Similar facts are seen in Glen Coul, where quartzite, with a gentle easterly dip, rests upon gneiss striking at high angles to W.N.W.

The "Logan Rock" being in the highest degree unconformable to the rocks both above and below, it can no longer be regarded as a member of a continuous series. If there is no dislocation, there must be two enormous breaks. Assuming the "Lower" Quartzite to be Ordovician, the "Logan" must be at least Devonian, and the "Upper" Quartzite can hardly be Palæozoic at all.

These reasonings have proceeded upon the assumption that in the "Logan Rock" foliation corresponds with stratification—a theory which, so far as I know, has never been disputed in reference to the



admitted Hebridean. If the foliation does not represent bedding, it represents current-lamination, cleavage, or something else.

Passing over current-lamination as obviously out of the question, let us examine the cleavage hypothesis. A few considerations will show its inapplicability.

(1) Cleavage-planes are uniform over large areas; but the planes in the "Logan" often dip, within a square rood, in more than one direction, their strikes sometimes bend sharply round, and they are contorted precisely as in the case of ordinary strata.

(2) Cleavage-planes cut across bands of varying composition; but the planes of fission in the "Logan Rock" coincide with such bands.

(3) Cleavage-planes are not confined to certain horizons, leaving rocks above and below which are susceptible of cleavage unaffected. But shales and grits which rest upon the "Logan Rock" in Ben More, and similar strata below the "Logan" of Glen Coul, present but slight traces of cleavage; and such cleavage as exists does not coincide in strike with the foliation of the gneiss.

If it be suggested that this foliation is the result of some unknown force, I can only reply that it will be time for me to examine this cause when it has been discovered. Meanwhile I am justified in working on the accepted principles of our science.

3. *The strata below the "Logan Rock" not metamorphosed.*—The "Logan Rock" is as highly metamorphic as the Hebridean, but the underlying rocks have undergone little change (see p. 359). Now I do not affirm the impossibility of contemporaneous metamorphic rocks resting on unaltered beds; but I do not know of such a relation in the British Isles. Such cases have, indeed, been alleged to occur in North Wales and Ireland; but after studying most of these instances in Wales and some of the most critical in Ireland, I am compelled to reject them, the apparent superposition of the metamorphic rocks having been ascertained, in every section examined, to be due to dislocation. When, therefore, we find highly crystalline gneiss overlying shales and slates, our experience in the British area raises a strong presumption against the contemporaneity of the metamorphic rocks. I have already shown (p. 359) that the phenomena cannot be explained by selective metamorphism.

4. *No beds of passage between the "Logan Rock" and the rocks above and below.*—If any formation intercalated between others had been metamorphosed, we should expect some signs of transition between the metamorphic and the unaltered rocks. Such evidence is, indeed, offered by Dr. Heddle. Thus he states that, on Camaloch, the "Logan Rock" occurs in the "Upper" Quartzite "in five closely adjacent beds." Having studied the locality, I am unable to accept this reading. There is abundant evidence of excessive contortion, crushing, and dislocation; and the alleged intercalations I believe to be merely repetitions by faulting. Similar facts are stated to occur in Glen Coul, in a section which I visited under the obliging guidance of Dr. Heddle. I was not satisfied with the evidence then adduced; and the facts collected at the time, confirmed

and enlarged by subsequent more deliberate study, led me to conclude that the supposed interstratification of "Logan Rock" was one of three things:—

(1) The seamy layers of the lower beds of the quartzite, greened by vegetation at the outcrops. These bands, when broken into, proved to be quartzose grit.

(2) Intrusive dolerite, which in one section was clearly seen to break up through lower beds, and spread itself out between quartzite strata. This rock bears some resemblance to certain green hornblendic bands in the gneiss; but it displays no signs of foliation, and has the characters of an ordinary dolerite.

(3) "Logan Rock" repeated by faults, the rock which succeeded it being in every case the well-known seamy quartzite.

I am not aware that a passage between the "Logan Rock" and the adjacent formations has been alleged for any other localities.

5. *Alteration and crushing of the "Logan Rock" at junctions with other formations.*—After having examined junctions in some scores of sections\*, I cannot recollect a single case in which the gneiss did not display signs of alteration at junctions. This evidence was seen in one or more of the following particulars:—

(1) The gneiss was green in colour, owing to the presence of a chloritic mineral (No. 63, p. 416). This mineral was either disseminated through the mass or occurred in thin folia.

(2) Even when there was no alteration-product present, the gneiss was usually soft and decayed, offering a marked contrast to the typical "Logan," which is tough and sound.

(3) The gneiss presented a confused, "messy" appearance.

These kinds of alteration are such as we expect to find at faulted junctions. Atmospheric waters, sinking down the fracture, would find ample material for the formation of hydrous magnesian silicates. The rotten state of the gneiss is accounted for by the decomposition which has taken place. In the partial dedolomitization of the magnesian limestone in contact with gneiss, already described (p. 362), we have an apparent example of the chemical reaction of the gneiss upon the dolomite.

The crushing of the gneiss in contact with newer rocks is very marked. This cause, combined with decomposition, often renders it impossible to obtain a clean fracture. The evidence is still clearer under the microscope (Nos. 63, 73, 74, 80, 81, 83–91, pp. 416, 417). A few of these specimens have a very fragmental aspect; and I think it possible they may be gneissic *débris*, highly altered. They are, however, regarded by Prof. Bonney as Hebridean crushed *in situ*, though his opinion is not free from hesitation†. The position of these perplexing rocks is always between the sound gneiss and

\* I include Ullapool in this generalization.

† [The sole reason for this hesitation was that the opinion was formed on the slides alone, knowing nothing of their stratigraphy; and now and then a crushed rock simulates to an extraordinary extent a true sedimentary rock. In several of the slides I had no doubt whatever I had "crushed Hebridean" before me.—T. G. B.]

the Assynt series; and for the purpose of this paper it is immaterial to which they belong. The majority of the above-named specimens are undoubted gneiss, taken from the "Logan Rock" near its faulted junction with other rocks.

6. *Strikes of the "Logan Rock" and Hebridean frequently concordant.*—It is usually affirmed that the prevailing strike of the Hebridean is north-westerly. This holds for some districts, but it only partially applies to Assynt. On the south side of Loch Assynt the strike is E.N.E.; and on the north side, where we first come upon it after leaving the Torridon, the strike is N.  $10^{\circ}$  W. Further to the north, on Loch Glen Coul and the slopes south of Kyle Sku ferry, the *dip* is to the N.W. at low angles; but, leaving the north side of the ferry, and following the path to the N.E., which leads to Loch More, the strikes are seen to vary frequently, my note-book furnishing the following changes, taking the strikes from west to east—viz. E. and W., W.N.W., W.S.W., N. and S., N.W., W.S.W., W.N.W., and N.N.W., the prevailing direction perhaps being north-westerly. Taking the Hebridean of Assynt as a whole, the variations are too great to permit a general induction.

Coming to the "Logan Rock," we have seen that its usual strike in the central masses of Ben More is N.N.E. or N.  $10^{\circ}$  E. In Glasven the foliation is to the N.N.W., concordant with the strike of the nearest Hebridean (on Loch Assynt). In Glen Coul the strike is N.W.; and in Glen Dhu, E. and W.—that is, more or less transverse to the strike of the undisturbed Hebridean under the Quartzite on Loch Glen Coul, but agreeing more nearly with the prevailing strikes on the road to Loch More; indeed the strike of the "Logan" of Glen Coul, if produced to the N.W., would coincide with that of the admitted Hebridean on the Loch More road.

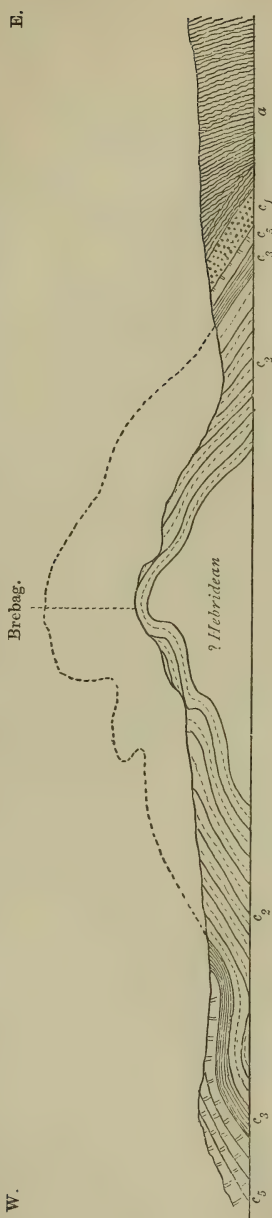
Comparing the "Logan Rock" as a whole with the Hebridean as a whole, the coincidences of dip and strike are greater. Thus, in the northern part of Assynt—that is, in Ben Uarran and Glasven, and between Lochs Assynt and More—the "Logan Rock" strikes westerly or north-westerly, as in typical Hebridean; and in the Ben More masses, though the strikes vary between a few degrees E. or W. of N., the dips are very high, frequently nearly or quite vertical, as is so frequently the case with the old gneiss.

### C. *Direct Proof of the Overthrow of the Hebridean.*

Many of the considerations already advanced point to the conclusion that the "Logan Rock" is the Hebridean gneiss brought up over the Assynt series by earth-movements. But evidence still more decisive can be adduced.

We have seen that the vertical or high-dipping gneiss of Ben More is overlain by horizontal conglomerate and grit (No. 94, p. 417), forming the base of the "Upper" Quartzite. The place of the Ben More Grit is then *above* the gneiss (Logan Rock). In the ground to the south this relation is reversed.

Fig. 5.—Section from Loch Maolack Corry to Dhuloch More. (Scale about 3 inches to 1 mile.)



Section up the Cascade from Dhuloch More (east end of fig. 5).—The facts here described occur within one mile to the south of the section to which reference has just been made. They are well seen in the wild gorge occupied by the infant Oykel as it cascades down from the elevated tarn of Dhuloch More (1500 feet). The bottom of the valley (900 feet) is formed of the Quartzite, which sweeps down in undulating sheets from the lofty ridge of Brebag. The dip is E.N.E. at  $15^{\circ}$ . This rock is continued up the stream to about 1000 feet, where it is conformably overlain by Brown Flags, *Salterella*-quartzite\*, and between 20 and 30 feet of the Dolomite. Thus far the succession is normal. Resting on the Dolomite, apparently in conformable succession, is about 100 feet of reddish felspathic grit (Nos. 92, 93, p. 417), which, towards the top, rises in dip to nearly  $90^{\circ}$ , and is overlain by red and green gneiss, with obscure bedding. A little higher up, this gneiss dips easterly at a low angle; and following it to the high ground above, it is seen to be continuous with that which forms the chief mass of Ben More.

The grit, overlain by similar gneiss, rather soft and decayed, can be traced for more than two miles to the south along the steep escarpment which overhangs the eastern side of the Oykel valley. The gneiss forms the vertical cliff crowning the scarp. Below it the grit occupies the slope, and is exposed in several small cascades. Towards the south, green grit begins to be intercalated with the red variety; and on the stream from Dhuloch Beg the colour is

\* This band, owing to its thinness, is not always inserted in the sections.



mostly green, the rock being of precisely the same character as the grit in the peak of Coniveall.

*Section up the Cascade from Dhuloch Beg.*—The lower part of the burn, just above the Oykel river, is occupied by drift and bog. The lowest rock seen is a slight outcrop of gneiss, dipping E.N.E. at  $45^{\circ}$ . Above this is green grit, with, in one place, the red variety, the total thickness being a little under 100 feet. Towards the upper part the rock becomes coarser, small pebbles coming in, then larger ones, till at the top we reach a massive conglomerate, undistinguishable from the rock which lies at the base of the grit in Coniveall. The larger pebbles, which are of highly altered quartzite, are from 6 to 8 inches in diameter. Some of the smaller ones are a granitoid gneiss, similar to ordinary Hebridean. This conglomerate dips E.N.E. at  $30^{\circ}$ , and is overlain by gneiss dipping E.N.E. at  $40^{\circ}$ . The two rocks are in immediate contact, the conglomerate being a little crushed and contorted. The gneiss can be traced up literally without a break into the massive gneiss of the southern ridge of Ben More. But the importance of the section requires more detailed description.

The gneiss (No. 73, p. 416) overlying the conglomerate is similar to ordinary granitoid Hebridean; but associated with it are some chloritic bands. Ascending the slope above the northern bank of the cascade, we find the prevailing dips of the gneiss are still at a low angle to E.N.E. Here and there, however, the foliation abruptly changes to vertical with a northerly strike. Continuing along to the north-east, round the cliffs on the north-west side of Dhuloch Beg, the usual dip is about  $20^{\circ}$  to N.E.; but further east it gradually rises to nearly  $90^{\circ}$ , with strike to the north. The precipices overhanging the N.N.W., N., and N.E. sides of the loch are formed of the gneiss, still almost or quite vertical, striking N.  $10^{\circ}$  E. Ascending Eagle Rock (2345 feet), I found the gneiss, with a northerly strike, right up to the summit. On the south-east slope lies a thin band of quartzite, dip S.S.E. at  $15^{\circ}$ ; but at the extreme south-eastern point of the mountain the gneiss reappears (No. 76, p. 415).

Returning to the Oykel valley, and working from the gneiss back to the conglomerate along a more southerly line, we observe similar facts. Leaving behind us the igneous mass north of Loch Ailsh, we reach our ground at about two thirds of a mile south of Dhuloch Beg. Climbing the scarp to a height of about 1000 feet, we first come to about 15 feet of quartzite, with red felspar bits, dipping south-easterly at  $30^{\circ}$ – $40^{\circ}$ , and underlain by a few beds of sandstone and grit. Then, between this point and the Dhuloch Beg cascade, half a mile to the north-north-west, we have the following descending succession:—

Massive gneiss, vertical, foliation-strike N.N.E.–N.E., probably on the strike of the vertical gneiss on the loch.

Do., underlain by soft mica-schist,

Do.,

Do.,

Do., at junction with conglomerate in cascade,

dip E. at  $60^{\circ}$ .

dip N.E. at  $70^{\circ}$ .

dip E.N.E.,  $60^{\circ}$ – $70^{\circ}$ .

dip E.N.E.,  $40^{\circ}$ .

We conclude from these two traverses that vertical gneiss striking to (roughly) N.N.E. gradually slews round to a north-westerly direction, and in the same graduated manner falls in dip to  $40^\circ$ , where it rests upon the conglomerate and grit.

We have here observed the following facts:—

(1) Red and green grit, which rests on gneiss at Coniveall, is overlain by the same gneiss (for there is no break in its continuity) in the southern sections.

(2) In Coniveall the grit terminates downwards in conglomerate, but to the south the conglomerate is at the summit, in both cases being in contact with the gneiss.

(3) The vertical gneiss in the Ben More *massif* gradually changes its strike and dip till it is seen to overlie the conglomerate.

These appearances seem to me inexplicable except on the supposition of an overthrow of the gneiss and grit upon the dolomite. But corroborative evidence may be adduced.

*Section at the north end of Scounan More.*—Scounan More\*, situated to the south-south-west of the last section on the opposite (the west) side of the Oykel, is a mass of gneiss with nearly vertical foliation, whose strike produced northward would coincide with the strike of the gneiss in Ben More. The rock is of the usual coarse, massive type, and is very distinctly foliated. At the north end the ridge falls down abruptly on to the col (Bealach Choinnich) which separates it from Brebag. This notch marks a fault, quartzite against gneiss. The junction is well seen in the steep slope down to the Oykel, a little south of the col. The gneiss dips S.E. at  $70^\circ$ ; and the quartzite is in actual contact, dipping to S.  $30^\circ$  E. at  $20^\circ$ ; but at a little distance the quartzite is nearly horizontal. I followed the dislocation downwards for hundreds of feet, and as a stream kept nearly to the fault, and washed the rock-surface clean of *débris*, the evidence was singularly clear. The gneiss was a little contorted at the junction, and rather decayed, besides being “messed” with chloritic matter. The great discordance of dip was steadily maintained.

Reascending to the pass, we find its steep southern side occupied by a dark-green shaly rock, passing *upwards* into a green grit† (No. 95, p. 417) of the usual Ben More type, which dips below the gneiss of Scounan. All the beds have a south-easterly inclination, the gneiss at a higher angle. The grit rests upon the quartzite, which abuts against the fault.

This section throws light upon those just described. We here see, as it were, the anatomy of the overthrow. The quartzite is thrown down against the gneiss in nearly horizontal beds; and the

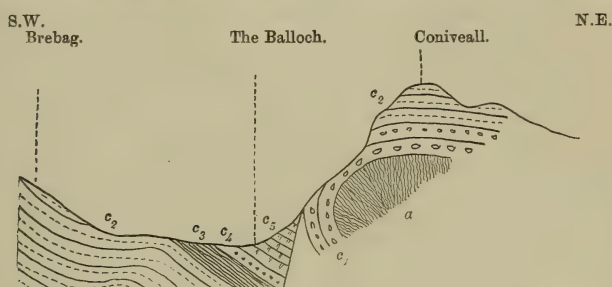
\* “Sgonnan Mór” on the Ordnance Map. Throughout this paper I have as far as possible used the naming of the Duke of Sutherland’s Map, as more nearly representing the pronunciation.

† It will be seen from his note that Prof. Bonney, without any knowledge of my views on this point, infers that the grit “appears to have been greatly compressed, as if nipped in a fault.”

high-dipping gneiss, with its overlying green grit, is, by powerful lateral pressure, bent over onto the younger formation. An outlier of the quartzite forms a thin sheet sloping down the south-eastern side of Scounan, corresponding to the patch on the Eagle Rock. These outliers are, of course, the "Upper" Quartzite of authors.

*Section across Coniveall.*—As the last section shows us how the Quartzite is brought under the Hebridean, the present one\* explains the mode in which the Ben More Grit is thrown onto the Quartzite

Fig. 6.—*Section across Coniveall.* (Scale 2 inches to 1 mile.)



series. High up on Coniveall, as already described, the grit rests horizontally upon the gneiss. Following the former towards the west, the beds are observed to gradually rise in dip for some distance in that direction: this fact was independently observed by Mr. Bailey in 1881. Then they bend right over, and plunge down the precipice which overhangs the Balloch. I could not descend the cliff far; but I was able to trace the beds down for some hundreds of feet with a glass. The upper part of the curve, however, was easily observed; and the rock was hammered over (No. 94, p. 417). Coming down to the Balloch, to the point vertically under, we find the whole thing reversed. Green and red grit, in broken masses, passes under gneiss dipping E.N.E. at  $70^{\circ}$ – $80^{\circ}$ . All the rocks are much disturbed and crushed; but the main facts are clear. This gneiss is a part of the same spur-like mass which *underlies* the grit above. The grit is thus seen to form a broken fold overthrown to the west, and enclosing a core of gneiss. On the west side of the pass the Assynt series, as we have seen, dips towards the gneiss and grit. We can now more fully estimate the difficulties of Murchison's statement that the limestone of the Balloch passes below the "Upper Quartzite" of Ben More.

This and the preceding section are mutually illustrative. The quartzite in both sections is identical, being continuous in sheets from

\* Compare this section with the description of the *western* scarp in my observations on the structure of the Assynt mountains. The western and south-western escarpments are on opposite sides of the fault.

end to end of the Brebag ridge. The gneiss of the two localities is also the same formation. The Scounan (Bealach Choinnich) section displays the fault, which in the Balloch (Coniveall) is only inferential; and the Balloch section reveals more fully the structure of the overthrow.

*Section up Glen Coul* (fig. 7, p. 391).—This important section, already noticed, must now be more fully described. Sailing up the sea-loch from Kylesku ferry, we pass a considerable thickness of grey Hebridean gneiss. At first the beds are nearly horizontal; then they begin to dip at a low angle to the N.W., and maintain this inclination up to about the middle of the loch, where they are overlain by the Assynt series, dipping at  $8^{\circ}$  to E.S.E. About half a mile further, a fault, seen in the precipices on both sides, throws up the Assynt rocks, which had dipped down to the sea-level, in broken but generally horizontal masses. Towards the head of the loch the inclination suddenly rises, and curves right over to the vertical. The crush at this point is such as I have rarely seen equalled. Masses of quartzite, flags, and dolomite are thrown together in inextricable confusion. Some beds, even of quartzite, are a mere mass of breccia. The rocks are exposed, as in a model, on the shore and in the islands; but the clearness of the ground only the more distinctly reveals the disorder. This locality is indicated in the section; but it would be impossible to represent the facts without mapping every yard of ground. Dolomite beds are thrown between flags and quartzite in such a way as to suggest true interbedding; but that they are mere faulted wedges is seen by following them along the strike. In one place two bands in actual contact displayed clearly a discordant strike. In another, masses of the same kind of rock had been brought together at different angles and recemented. At the east end of this crush, where the Hebridean overlies, the rocks are less disturbed, the ordinary divisions of the Assynt series following each other in curved beds dipping on the average at  $60^{\circ}$ . The direction of dip varies between E.S.E. and S.S.E., owing to a bending-round of the strike. At the junction on the shore, dolomite, from 10 to 15 feet thick, passes with apparent conformity below the Hebridean (Logan Rock). The gneiss is chloritic, and so much decomposed and jointed that a clean fracture could not be procured. The curvature of strike is also seen in the gneiss, a fact which at first sight might suggest conformity.

At the back of the house the dolomite is much thicker, occupying the breadth of a small field. Thickening out to such a degree within a hundred yards or so is out of the question. So abrupt a change at once suggests unconformity.

Ascending the precipices which overhang the north side of the loch, the most striking facts are disclosed. Right along the cliffs, for more than a mile to the west, at a height of about 100 yards, the old gneiss (No. 75, p. 415) rests upon the Assynt series. The younger rocks, as just described, lie at various angles; but the gneiss dips steadily to the N.E. Taking the two groups as a whole, the strike



of the gneiss is parallel to the loch, while the underlying quartzite and dolomite strike across the loch.

The discordance between the gneiss and the rocks which overlie is equally marked, as previously described.

This remarkable ground throws new light upon the similar sections further south. The valley having been cut across the strike of the Assynt series, we see the internal structure of the overthrow. The curvature, accompanied by excessive crushing, so clearly seen at the head of the loch, is just what we should expect to find if the beds were broken off, and then pushed laterally by the force which threw over the gneiss. The masses of "Upper" Quartzite up the glen are simply undenuded fragments of the Assynt rocks remaining on the east side of the fault.

The older and newer groups hold similar relations to each other for several miles to the north. On Loch Glen Dhu the Assynt rocks, smashed into fragments, are overlain by the gneiss striking at a discordant angle.

I have not examined the east end of the section on Loch More, described with such different interpretations by Murchison and by Nicol; but at the western end I found the Quartzite and Brown Flags succeeded by the granitoid gneiss of Craig Dhu, no signs of actual overlie being visible. Nicol's north-westerly dip of the quartzite away from the "igneous rock" is, I fear, a mere matter of jointing. The region between this point and Loch Erriboll I have not studied.

*Ground between Coniveall and Glen Coul.*—The dislocation which passes through the Balloch follows the western escarpment of Coniveall, and is apparently continuous along the west of Ben Uarran with the Poulan-drein fault, unless, indeed, the throw dies out at the sharp curve near Glenbain. On this line the proof of lateral thrust is similar to that described further south, as seen in the overthrown folds of quartzite at the west end of Ben Uarran, in Cnoc-an-drein, and on the Burn of Calda, though, of course, the action of the force is much weaker. I believe the fault passes from Calda Burn along the west side of Glasven; but the country is too obscured by débris to furnish other than inferential evidence. From Glasven the dislocation is continued by Loch na Gamvich to Loch Glen Coul.

*Section on Camaloch.*—The Hebridean which appears here lies four miles to the west of Seounan, the nearest point of the main mass of "Logan Rock." The rocks are largely covered; but the following facts are fairly clear. The section is from west to east. On the stream which falls into Camaloch from Loch a' Chroisg the Quartzite, resting on Torridon, dips at a low angle to the east, and after a short interval there is a slight exposure of Brown Flags in their usual place. Drift then hides the ground, and the next rock seen is quartzite of the seamy type, with bits of red felspar and associated "porphyry," overlain by Hebridean gneiss. Following the strike down to the shore, the Quartzite is seen to be excessively shattered and contorted. There is in this section evidence of inversion, gneiss

and seamy quartzite being thrown over onto the Brown Flags, and, perhaps, the Dolomite masked by the drift.

Following the inverted quartzite to the north, and circling round the north end of the hill to its eastern slope, we keep continually upon quartzite; so that it would seem as if the Hebridean were enclosed in an overthrown fold of the quartzite, just as it is wrapped in a fold of grit in Coniveall. The ground, however, is so obscure that, without the key furnished by our previous studies, it would be difficult to arrive at even a probable conclusion.

#### D. *The "Upper Limestone" non-existent.*

##### (a) *The Dolomite repeated.*

The dolomite of Glen Coul and Rhie Cnoc, being a part of the eastern outliers of the Assynt series, are, of course, merely the ordinary dolomite repeated.

##### (b) *A part of the Caledonian Group.*

The crystalline limestones of Loch Ailsh were considered by Murchison and his followers an upper limestone of the Quartzite series; but by Nicol they were regarded as the Assynt series metamorphosed by contact with igneous masses. After devoting nearly a week to the study of the ground, I arrived at the conclusion that these rocks were a part of the Eastern Gneiss, and therefore of Archæan age.

Prof. Heddle holds that these limestones are divisible into two zones, separated by a band of "hornstone porphyry," which runs along the western base of Cnoc Chaorinie (Chaoruinn). The lower, which he considers a true marble, "apparently sweeps round to the south of the hill Scounan." The upper, which he describes as "not perfect in its metamorphism, and approaching in character to a granular limestone," is continued on the strike to the north, and, according to Murchison, "sweeps round to the east and north of the mountain of Ben More, and extends up the valley of the Cassley to the side of the Stack of Glen Coul." I will first discuss the last statement.

The limestone which is seen at the side of the high road east of Loch Borrolan, near the turning to Ben More Lodge, can be traced along the western face of Cnoc Chaorinie, up the eastern side of Loch Ailsh, and on by Ben More Lodge to about a mile north of Kinloch, a distance of nearly four miles. It tapers towards the northern end, and disappears beneath an extensive deposit of boulder-clay covered by bog. A little beyond, the "porphyry," which has been flanking the limestone on the west, comes up to the Caledonian, so as to cut out the limestone. I traversed the ground for miles to the north, and found nothing but drift and bog between the eastern gneiss and the quartzite of the Ben More *massif*. These facts, therefore, do not confirm Murchison's view. The "limestone" near Glen Coul, apparently the dolomite at Rhie Cnoc, is separated from the Loch Ailsh series by several miles of covered ground; so that no

connexion between the limestones of the two localities can be proved.

It is first of all necessary to examine the *chemical* characters of these rocks. There are two well-marked varieties—a cream-coloured dolomite affected but slightly by hydrochloric acid, and a white or grey marble effervescing freely under the test. The crystallization of the marble is usually coarser than that of the dolomite. The former type predominates in Dr. Heddle's lower series, and the dolomite in the upper. It is, however, important to notice that neither variety is confined to either subdivision. Dolomite of precisely the same type as that which prevails in the upper zone is interstratified with the marbles of the lower; and near Kinloch Ailsh I found abundance of the grey variety amidst the beds of dolomite. I have also detected the crystalline dolomite further west in association with the well-known marbles of Ledbeg. I do not, therefore, see any reason for separating the Loch Ailsh limestones into two distinct groups, though it is convenient to record that dolomite prevails in the upper part and marble in the lower.

I concede, contrary to the view of Nicol, that this limestone, at its upper margin, is clearly intercalated with the Eastern Gneiss.

That this limestone is a member of the Assynt series appears to be at once disproved by its chemical composition. The Assynt rock is a dolomite, and everywhere a dolomite. If it be suggested that metamorphism may have caused dedolomitization, I reply that marble is in several localities clearly interbedded with dolomite, and that it is incredible that the metamorphosing agent should have altered a stratum and left the beds above and below it unaffected. I have also a right to ask for proof that intrusive igneous rocks, the assumed cause of the change, are capable of converting dolomite into calcic carbonate.

The lithology of the Loch Ailsh series is in other respects dissimilar to that of the dolomite. In the latter, throughout its whole length from Loch Broom to the North Sea, I have never found a single quartzose bed; but the former contains towards the top a strong band of quartzite (No. 101, p. 418), which may be traced from the high road to near Ben More Lodge, where it is associated with calcareous schist (No. 105, p. 419), quite unlike any rock in the Assynt group. This quartzite, as will be seen from Prof. Bonney's note, is more highly altered than the ordinary quartzite of the younger series (No. 100, p. 418).

I have not been able to find in the Ledbeg marble, the presumed equivalent of the Loch Ailsh limestone, any support of the view I am controverting. I have studied numerous sections of this rock between Loch Ailsh and the hill-slopes west of Ledbeg, a distance of five miles. Everywhere it appears to lie in isolated fragments. North-east of Luban-Cromah its bedding is nearly vertical, striking to the north-west, parallel to the Hebridean ridge of Scounan. About a mile above Loyne, on the south bank of the Ledbeg river, marble, grey and yellow, in nearly horizontal beds, comes within a yard of unaltered dolomite of the Assynt series, dipping west; but the marble is



brecciated, and a fault evidently intervenes. A little further west marble appears not far from quartzite, and again near the high road ; but in neither case are the rocks in contact. Near the farm of Loyne, on the north side of the river, marble dipping north-east is overlain by igneous rock ; and 100 yards to the west is dolomite with a low easterly dip. Round Ledbeg, marble, quartzite, and dolomite occur in several patches ; but, so far as I have seen, there is always a break between the marble and the other rocks. On the slopes to the west the marble displays Eozoonic structure (No. 106, p. 419), first observed by Prof. Heddle. Quartzite is close at hand ; but here again there is no visible connexion. The marble of Ledbeg is usually a nearly pure calcium carbonate.

Now, if the marble is simply the dolomite altered (for any calcareous rock of the Assynt series except dolomite is out of the question), it is very remarkable that the two rocks should be often seen in proximity, and yet that there should be no evidence of a passage between them. Great masses of igneous rock, culminating in Cnoc-na-Strone, lie close at hand ; and smaller intrusions are here and there visible in contact with the marble ; but patches of dolomite within a few yards remain unaltered. Such facts are to me inconceivable on the supposition that the marble and the dolomite are of the same age.

We must next consider the relations between the Loch Ailsh limestones and the rocks which bound their western margin. If the limestones belong to the Assynt series, an unbroken succession must be proved between them and the beds below.

Working toward the south-east from Altnagalach, we come, at about  $2\frac{1}{2}$  miles from the inn, to quartzite dipping at a low angle to E.S.E. Fifty yards further on is dark-green gneiss with the same dip, overlain in conformable succession by siliceous flaggy beds, quartzite, dolomitic limestone of the Loch Ailsh type, and quartzite. This section is on the strike of the Loch Ailsh limestone, and it displays thin-bedded gneiss *below* dolomite, confirming the view that the limestone is *in* the Eastern Gneiss.

We next run a section parallel to the last at about half a mile to the north-east. Starting from Loch a' Mheallian, we leave behind us the great igneous mass to the north of Loch Borrolan ; and descending the slope to the south-east, we reach a small exposure of granitoid Hebridean gneiss (No. 79, p. 416), without distinct foliation. Then we come abruptly upon the marble and dolomite, which are continued with a steady south-easterly dip as far as the road to Loch Ailsh, and just beyond, in the slopes of Cnoc Chaorinie, are interstratified with Caledonian.

On the west bank of the Oykel, south of Kinloch Ailsh, the Quartzite of the Assynt series, which slopes down from Scounan, is seen with its normal south-easterly dip ; and on the opposite bank there are a few feet of the Brown Flags (Nos. 103, 104, p. 418) overlain by quartzite. The Loch Ailsh limestone appears in force a short distance to the south-east. Further north, the igneous rock soon cuts out the quartzite, and then the limestone itself.



The section just described appears at first sight to be the normal Assynt succession, with the limestone metamorphosed. It is the most serious difficulty I have encountered; but I have represented the facts without extenuation. I may observe that the occurrence of the flags in their regular position is strongly confirmatory of my views on the "Upper" Quartzite; but that is a minor point. If the succession here is unbroken, I must admit that the Eastern Gneiss is newer than the Assynt Series. But there is the strongest reason for placing a fault between the flags and the limestone. For, as we have seen, if we follow the limestone to the S.W., we find it in one place immediately underlain by Hebridean, and in another underlain by and intercalated with the Caledonian. Unless, then, we admit that the quartzite and flags pass into Hebridean, and then into the thin-bedded gneiss, we must concede the existence of a fault.

To summarize the facts described, we have the following reasons for separating the Loch Ailsh limestone from the dolomite of the Assynt series:—

- (1) The former is metamorphosed; the latter is not.
- (2) The former is largely composed of calcium carbonate; the latter is everywhere a dolomite.
- (3) There are nowhere any signs of a passage between the two.
- (4) The former is intercalated with quartzite, and sometimes with gneiss; the latter is dolomite from top to bottom.
- (5) There is strong evidence of a fault between the former and the lower members of the Assynt series.

#### E. *The Caledonian brought over the Assynt Series by a Reversed Fault.*

Our previous discussions having cleared up some preliminary difficulties, we are now prepared to investigate the main question, Does the Eastern Gneiss conformably succeed the Assynt Series?

*The Knockan Section.*—By Sir R. I. Murchison and Dr. Geikie the newer gneiss of this locality is said to conformably overlies the Dolomite; but Nicol places a fault between the two. The rocks are clearly exposed in the escarpment overhanging the high road; and some of the phenomena appear to support the Murchisonian view. Doubt, however, is thrown upon this interpretation by the fact that, a short distance east of the section of Murchison and Geikie, the strike of the Dolomite suddenly twists round through a right angle, while the strike of the gneiss remains unaltered. This seems to be inexplicable, except on the hypothesis that the Dolomite had undergone considerable dislocation before the gneiss was brought over it.

But a more serious difficulty remains. Within about a mile of where the newer gneiss rests upon the Dolomite, lies the Camaloch mass of Hebridean. This massive gneiss occupies a considerable breadth of country, and can hardly be less than several hundred feet thick. As its place is, *ex hypothesi*, between the Dolomite and the Caledonian, it follows that this great mass of rock, together

with its associated "Upper" Quartzite, has thinned out in a little over a mile!

After the preceding evidence of the overthrow of the Hebridean from end to end of Assynt, I think I am justified in contending that the mere superposition of one rock upon another is insufficient proof of true conformity. At Knockan we have simply an overlie of the gneiss along the strike; and we have no opportunity of examining the relations of the rock on the dip. For this purpose we want a valley or ravine cutting so deeply into the strata along the dip as to expose the true anatomy of the district. Such an exposure is furnished us by the next sections.

*Sections on the North and South Sides of Glen Coul* (fig. 7).—The region lying north of Loch Ailsh is so thickly covered that no junctions are visible for several miles. In Glen Coul, however, the conditions are very favourable for our purpose. The valley is cut down so deeply as to expose the relations between the Hebridean, the Assynt series, and the Caledonian, almost as in a diagram.

At first sight, indeed, the phenomena appear to favour the old view almost as strongly as the Knockan section. The Stack of Glen Coul is formed of the newer gneiss; and at its western foot quartzite seems to pass conformably below it, the two rocks being almost in contact. The ridge on the opposite (north) side of the glen exhibits similar appearances. Here also the newer gneiss forms a prominent peak; and in like manner at its western base, the quartzite, followed however by flags and dolomite, appears to dip below the gneiss. Following the junction for about a mile to the north, I found the same relations, except that the flags and dolomite were wanting.

Investigating the ground more closely, I ascertained new and very striking facts. As we ascend the southern ridge, which leads from the sea-loch up to the Stack, we pass over three exposures of quartzite with Hebridean between. It might at first seem that the quartzite was interstratified with the gneiss; but this is certainly not the case; for, on examining the slopes below, we find the quartzite beds are not continued on the dip. Of some weight also is the fact that both the lowermost and the uppermost of the three masses have the ordinary seamy quartzite at the base. I therefore regard these as faulted outliers of the quartzite on the loch to the west.

The quartzite outlier in contact with the Caledonian is of course the most important. Detailed study proved that the appearance of conformity was only superficial; for, while the Caledonian dips at  $15^\circ$ , the angle of the quartzite is  $35^\circ$ . The latter is of the annelidian variety; but the tubes are distorted. The rock is intensely squeezed, so that a coarse cleavage is produced, the particles of quartz are flattened, and there is a mineral change, the aspect being distinctly that of a partially metamorphosed rock (No. 98, p. 417). Following the strata down the slope to the N.E., we find that, instead of passing up into gneiss, the quartzite *rises* in dip, and is *overlain by the Seamy Quartzite* (No. 97, p. 418), which becomes almost vertical, the beds, however, curving over to the west. This quartzite has the

red felspar bits of the lowest zone. The pressure to which the rock has been subjected has flattened the quartz grains; and the cleavage and alteration are similar to those of the Annelidian Quartzite above. These beds actually lie to the east of the junction, so that on the strike they pass under the almost horizontal gneiss. East of this point the Hebridean rises up and meets the newer gneiss. It is therefore evident that this mass of quartzite is a syncline sharply folded back upon itself, and closely squeezed in the angle between the older and younger gneiss.

The curved beds of quartzite on the slope present a curious phenomenon. The joints are almost at right angles with the bedding, and are open much wider than the planes between the beds; so that at a distance the quartzite appears nearly horizontal, and the seeming beds are contorted. This twofold disturbance, the folding-back of the true beds and the contortion of the slabs between the joints, points to excessive lateral pressure acting from the east.

I have said that the Hebridean rises towards the east, so as to meet the Caledonian. This is more clearly seen by descending to the level of the stream. A little below the reversed fold just described, and a few feet above the stream, is a band of conglomerate about 4 inches thick. The pebbles, which are of quartz in a matrix of small bits of quartz and felspar, are flattened as if by pressure. This seam is undistinguishable from a thin band which forms the base of the quartzite on Loch Erriboll. It dips to the N.W. at  $20^\circ$ , and it rests immediately upon grey Hebridean gneiss, to the surface of which it is plastered. The gneiss has its normal strike to the N.W. The dip of this conglomerate shows us that the surface of the gneiss slopes up towards the east, and it confirms the previous evidence as to the reversed dip of the quartzite. Following up the junction, we soon lose the conglomerate under bog; but the Hebridean can be traced up the slope at about the same angle, gradually rising to the east of the quartzite to meet the overhanging Caledonian.

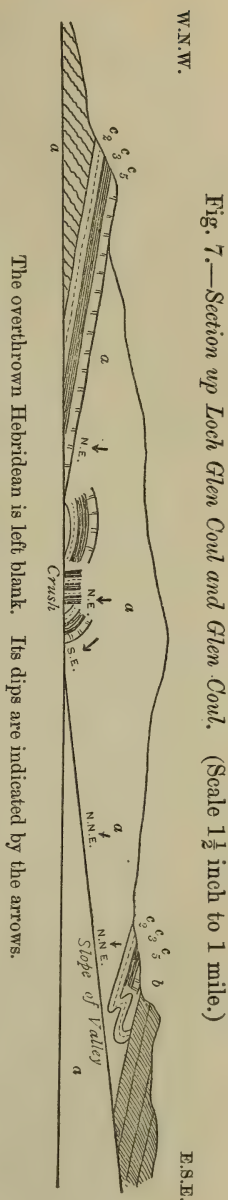


Fig. 7.—Section up Loch Glen Coul and Glen Coul. (Scale  $1\frac{1}{2}$  inch to 1 mile.)

We now come to the section on the north side of the valley. Leaving the shepherd's house on the shore of the loch, and ascending the glen, we pass over Hebridean with N.N.W. strike, which is continued, with few exceptions, up to the Quartzite. A few feet below the Quartzite the gneiss becomes rotten, and changes to the dip of the former. The Quartzite has at its base a band of red felspathic grit, and encloses red felspar bits. It dips steadily up the glen for some distance; then, when it becomes overhung by the Caledonian, it is squeezed up into a series of small folds thrown over to the N.W. The most easterly of these are on the strike of the overthrown fold on the opposite side. A little further east, the Caledonian comes down to the stream, the bed of which is occupied by the Hebridean. The ground just here is masked by talus of newer gneiss, so that no junction can be seen; but the lowest visible Caledonian is within 50 feet vertically above the Hebridean; and continuing with the eye the strike of the Caledonian across the glen, it seems as if it must actually touch the Hebridean. This is confirmed by taking the heights with the aneroid. The Caledonian on the northern slope descends to at least 925 ft., while the Hebridean just over the stream rises to 950 ft., which, allowing for the slight slope of the Caledonian beds from south to north, would about correspond. Beyond this point the Caledonian still descends on the dip to the east; so that the actual contact of the older and younger gneisses cannot admit of doubt. Now, as the Assynt series in this locality is at least 200 ft. thick, it obviously cannot pass to the east.

I infer from the facts described, that by a reversed fault the Quartzite has been broken off and crumpled up in the angle between the overhanging Caledonian and the underlying Hebridean. There will be little *a priori* difficulty in accepting this conclusion after studying the enormous overthrows of the old gneiss within two miles to the west. There can be no doubt that the overthrow of the Hebridean and the reversed faulting at the junction with the Eastern Gneiss are due to the same general cause.

As the dips of the Caledonian are to E.N.E. and E. at  $15^{\circ}$ , while the Hebridean dips at a high angle to N., N.N.E., and sometimes N.E., the unconformity between the two gneissic groups is well marked.

#### F. *Structure of Assynt.*

The preceding sections have anticipated much of what comes under this head; but it will not be uninteresting to bring together into a connected whole the facts which throw new light upon the mountain-structure of this remarkable district.

The lofty mountains have always been justly regarded as amongst the most interesting features in the scenery of Assynt. From a distance they appear like peaks of snow; and even on closer examination many of them seem to be composed of quartzite from base to summit. Hence writers have supposed them to be solid masses of that rock, and formations of quartzite thousands of feet thick have been described. This appearance is quite illusory. The quartzite is merely a sheet, about 300 feet thick, wrapping round



cores of Hebridean gneiss, but no more constituting the mountain it encloses than if it were a permanent mantle of snow or ice.

The western mountains, consisting of Torridon sandstone capped by the quartzite, have already been described by authors. My observations refer chiefly to the Ben More mass and the ranges which radiate from it.

*Scounan More*.—Usually regarded as “igneous,” but by Dr. Heddle as “Logan Rock.” It is a mass of nearly vertical Hebridean. On the south-eastern slope a film of quartzite dips down towards Loch Ailsh.

*Brebag* (2670 ft.) (fig. 5, p. 380).—This linear mass, striking N. and S., continues the Scounan ridge onto Ben More. It is entirely swathed in quartzite, which is compressed into a sharp anticline along the summit, with gentler curves on each side. On the western slope the folds are closer than on the east, and are overthrown. This quartzite thus resembles a wave blown along by an easterly wind, the slope on the east side being gentle, while on the west the crest falls over. This structure is another proof of the action of the lateral force from the east which produced the striking effects already described.

*Ben More* (3273 ft.).—We have seen that the old gneiss rises to 2500 feet in this mass, the capping being of the quartzite with the Ben More grit and conglomerate at its base. The great spur which projects to the south nearly halfway to Loch Ailsh is nearly all gneiss, a thin sheet of quartzite resting only on the highest parts, as described on Eagle Rock, which terminates the *massif* on the south. The precipitous western escarpment of Coniveall is also covered in by quartzite—not, however, in sheets plunging down to the west, but in beds dipping gently into the mountain. Ascending from this side, there is therefore the appearance of a great thickness of quartzite. That these strata are broken off is certain; for we know that the gneiss passes through the middle of the mass to within 500 or 600 feet of the summit. Nothing but a knowledge of the minute differences visible within the quartzite series would here help us to a solution.

The following facts were seen in ascending the Traligill to the col between Ben More and Ben Uarran. At the foot of the cascade (925 ft.) is a considerable thickness of the Brown Flags, succeeded by quartzite, and at 1100 ft. by dolomite. There is no great thickness of this; and at 1175 ft. quartzite of the annelidian type comes in. Towards 1475 ft. the quartzite rises gradually to the vertical, and is thrown over, the seamy bands being uppermost; and rock of this variety occupies the scarp up to the pass (2025 ft.). Intrusions of igneous rock have been frequent from near the base of the section to this point, some of the masses being of considerable thickness. In some places the igneous rock is interbedded. The dip of the quartzite has been easterly at a low angle. With the key already furnished to us, the explanation of these facts is not difficult. I am satisfied that the Balloch fault passes round the face of Coniveall, and that in the section just described the quartzite is thrown down against

the steep western face of the faulted Hebridean, and is repeated more than once by step faults. Just below the col on the eastern side of the ridge the gneiss is exposed, proving to demonstration that the quartzite beds are not continued to the east.

At the col is a plateau paved with the Annelidian Quartzite dipping gently down from the peak of Coniveall, *i. e.* to the N.W. Rising on the east side of this plateau is a cliff 200 ft. high, composed of a repetition of the Seamy Quartzite, with interbedded igneous rock. This band appears to be continuous with beds which roll down from Coniveall; but the slopes up to the peak are too thickly masked by quartzite fragments to permit the examination of rock in place.

While ascending Coniveall from this pass, we have to our left the sharp ridge which connects this peak with Ben More proper, and we can clearly see the capping beds of quartzite, lying horizontally, or dipping gently in an easterly direction. The summit of Coniveall is composed of the Seamy Quartzite, with low north-easterly dip; but on the south-east side the dip is south-easterly. The quartzite is thus seen to dip with the slopes of the mountain on the three accessible sides; the fourth, the south-western, a lofty precipice, is the upthrow side of the Balloch fault.

*Ben Uarran* (2644 ft.).—This ridge is a spur of Ben More, projecting towards the north-west. According to Dr. Heddle, it is formed of an anticlinal fold. I have observed that the plateau along the summit consists of the Quartzite, in part, at least, Annelidian, and that this rock plunges down on the S.W. side; but I have not examined the N.E. slope. I have, however, no doubt of the accuracy of Dr. Heddle's description, since it corresponds with the normal structure of the Assynt mountains. The old gneiss reappears at the N.W. end.

*Onoc-an-drein*.—This hill is really a part of the Glasven ridge, separated from the main mass by the narrow col occupied by the Burn of Calda, and running out to the S.E. to meet Ben Uarran. The quartzite in which it is enveloped rolls off in sheets to the S.W., S.E., and N.E.; but to the N.W. the outcrops of its beds form a semicircular escarpment facing Glasven. At Calda Burn the Hebridean emerges, rising up into Glasven; and the quartzite is seen to wrap round the old gneiss, just like a shoe enclosing the foot, with the instep showing above.

*Glasven*.—From the Burn of Calda nearly to the summit, the ridge is all Hebridean, the final elevation only being capped by the quartzite. The spur to the N.W., which I did not examine along the top, is shown in Dr. Heddle's map as an anticlinal saddle; but the old gneiss reappears at the end, where the ridge falls down on Loch na Gamvich.

*Ben Uie (Uidhe)* (2384 ft.).—This ridge, which runs parallel to Glasven on the east, I did not visit. On Dr. Heddle's map it is represented as "Logan Rock" on the east side, with quartzite capping the summit and dipping down to the north-west. Messrs. Eccles, Miall, and Tiddeman, who examined the western slope, informed me that the quartzite occurred in at least one overthrown fold. This

fact corresponds with what I have described as the usual position of the quartzite on the western slopes of the Assynt ranges.

*Ben-na-creisag and Ben-an-Uarran*\*.—These are the two reddish-looking hills which overhang the road south of Inchnadamff on the east side, between the igneous mass of Cnoc-na-Strone and the Stronchrubie cliffs. On Prof. Heddle's map they are coloured as "quartzite," but with a query. I have examined both from end to end, and believe them to be blocks of Torridon Sandstone thrust up between faults through the overlying members of the Assynt series. At the south end of Ben-an-Uarran, the rock closely resembles the red grit of Ben More; but further to the north it passes into red sandstone of ordinary Torridon type. Ben-na-Creisag is of similar rock, conglomerate as well as sandstone being present. The dips were usually not very clear, but in Ben-na-Creisag they seemed to be to the N.W. Descending to the west from the summit of Ben-an-Uarran, we first come to quartzite of the seamy variety, with red felspar bits, dipping into the hill; and beyond a little hollow is white dolomite, which is first vertical and contorted; then it dips into the ridge; lower down it dips away from it, and finally, near the road, into the hill again. These facts point to inversion of quartzite upon dolomite, an effect which would naturally be produced by the upthrust of the Torridon, with lateral push from the east, just as similar results have followed from like causes in the mountains further east. Dolomite dips away from this hill at the north end. The Torridon mass of Ben-na-Creisag appears to be entirely surrounded by dolomite, which in some places dips towards it, and in others away from it, the junction being frequently marked by a line of débris.

*The Stronchrubie Basin*.—This mass of dolomite approaches in shape an equilateral triangle, the sides respectively facing to W., N.E., and S.E. The western edge crops out in the well-known escarpment which overhangs the road south of Inchnadamff, the strata dipping easterly. Along the north-eastern margin the quartzite of Ben Uarran passes below the dolomite, the dip being to the S.W. To the S.E. the quartzite of Northern Brebag dips conformably below the dolomite above Loch Maolack Corry, the inclination being to the N.W. The dolomite therefore forms a true basin, the strata dipping inwards from the three sides.

From the facts adduced it will be seen that Prof. Nicol's description of Assynt is in its main points confirmed. He interprets the structure of Ben More as "a nucleus of granitic gneiss and mica slate, with intrusive igneous rocks, throwing off the quartzite all around, as from a great centre of elevation;" and this, omitting the "igneous rock," which seems to have been his interpretation of the overthrown Hebridean, is substantially accurate; and he truly affirms that "the limestone is everywhere troughed by the quartzite."

\* This name must not be confounded with "Ben Uarran."



## LOCH ERIBOLL.

The evidence for the overthrow or overthrust of the Eastern Gneiss upon the Assynt series is even clearer here than in the southern localities. The proof is indeed so distinct that nothing but the hastiness of most previous workers can, I think, account for their failure to perceive the true interpretation. Prof. Nicol, who probably gave more time to the district than any of my predecessors, saw more clearly into the structure of the region than his contemporaries; and I am glad to be in a position, however humbly, to vindicate his reputation. From a prolonged study of the district in the summers of 1881 and 1882, I am able to supply much additional evidence, and to correct some errors of interpretation into which he fell. The chief of these misapprehensions has reference to the rock which he called "granulite;" and it will be well to clear up this point before attacking the main question.

A. *The "Granulite" of Nicol a lower division of the Caledonian.*

Cunningham held that in Ben Arnaboll (Poll Ath-roinn), the "Upper" Quartzite was conformably overlain by "gneiss;" and Murchison confirms this view, except that he describes the upper rock as "chloritic, talcose, and micaceous schists." I hold, with Cunningham, that the rock is a true gneiss; indeed I have rarely seen a more typical gneiss; but its exact lithological composition has no material bearing on our inquiry. I concede to these authors that the gneiss does overlie the quartzite, though I will not say "conformably." Nicol also saw this overlie; but he evaded the difficulty by affirming that the whole of the upper series was an intrusive rock which he called "granulite."

This "granulite" not only forms the higher part of Ben Arnaboll, but it is exposed to the breadth of over half a mile in the valley to the south, up which the path to Arnaboll runs. For convenience we will call this the Arnaboll valley. Nicol says that in this section the "granulite" "throws off the strata on each side, and involves large fragments of the mica slate, with the laminæ turned in various directions." From this reading I decidedly differ. The valley shows a very clear section of bedded rock, the series ascending from W. to E. At the west end, apparently overlying the "Upper" Quartzite, is a grey and pinkish granitoid gneiss, passing up into a considerable thickness of rather massive gneiss, striped with folia of hornblende and dark mica (Nos. 64, 77, 78, pp. 415, 416). Towards the east this rock grows lighter in colour, and the bedding becomes thinner, till, about the water-parting between Lochs Erriboll and Hope, it passes up into the ordinary flaggy type.

The Arnaboll gneiss bears some resemblance to Hebridean: indeed Prof. Bonney, judging from hand-specimens only, refers it to that formation. But field-work does not confirm this opinion. The conformity of the Arnaboll rocks to the Hope series is seen in strike, in dip, in the unbroken sequence, as observed on many lines of section, and in the gradual transition in mineral and lithological



characters. Besides this, though a few typical specimens may resemble some varieties of the old gneiss, there is no great difficulty in differentiating the two gneisses when we compare them in the mass. In the newer group mica is incomparably more abundant; there is a larger proportion of a pinkish-grey, rather fine-grained, granitoid gneiss, quite different from any I have seen in the Hebridean; and there is that undefinable assemblage of minute characters which we may call the "habit" of a group.

Further light is thrown upon this question by the gneiss at Sango Bay, Durness, described in my former paper. The resemblance of this rock to the Arnaboll group struck me in 1880. The Durness gneiss has undergone considerable alteration, chloritic minerals being developed; but the general characters of the two rocks are similar. In Durness the Hebridean steadily preserves its typical north-westerly strike, the beds being nearly or quite vertical; while the Sango Bay gneiss dips at low angles conformably, though not in actual contact, with the flaggy gneiss of Far-out Head. If then, as is probable, the Sango Bay gneiss is the equivalent of the Arnaboll rock, we are furnished with an additional proof of discordance between the Hebridean and the Arnaboll group.

But the undoubted Arnaboll gneiss, in its north-easterly extension, is only separated from the Hebridean of Ben Keannabin by the breadth of Loch Erriboll, within 2 miles; yet the strike of the newer series is as steadily to the N.N.E. as that of the old gneiss is to the N.W.

The Arnaboll gneiss is literally "riddled" by a binary granite of quartz and felspar, which is sometimes more prominent than the gneiss; and this has apparently led Nicol to the conclusion that it was the prevailing rock, which had "caught up fragments of the mica slate." Further particulars of this series will appear in the sequel.

### B. *The Assynt Series folded back upon itself.*

*Structure of Druim-an-tenigh.*—This quartzite ridge overhangs the road from above Heilem Inn to the west end of Arnaboll valley, a distance of about two thirds of a mile. It strikes due N. and S. It is the first ground which should be examined by any one wishing to read the riddle of the district.

I ascended the ridge from the east side, just at the north end. Here I found quartzite of the seamy type, with a grit band 10 feet above the base, just as in Assynt. The beds were horizontal or with a slight dip to the E. Following the strata across the ridge, they are seen to bend abruptly over, and plunge down at a high angle to the W. We now turn south, and, keeping along the strike of these strata, we find the dips grow steeper and steeper till the vertical is reached. Then the beds begin to overhang, the overthrow increasing till, at the southern end, just at the opening of the Arnaboll valley, they dip easterly, apparently passing below the Arnaboll gneiss at moderate angles, from  $50^{\circ}$  to  $60^{\circ}$ . The quartzite has still the seamy

and gritty characters always to be observed at the base. Some of it is brecciated by crushing.

Turning to the west, we descend the slope to the Loch. The dip of the quartzite becomes less and less steep, till, in the shore, it is about  $15^{\circ}$ , and is of the Annelidian type. This dip is continued to the north along the beach to nearly opposite Heilem ferry. Here the Dolomite occurs at a short distance to the west, but no junction is visible.

*Without leaving the bare rock*, we have thus traced the quartzite from the horizontal right over to almost the horizontal in inverted position. No clearer evidence of overthrow can be desired. Yet this is the "Upper" Quartzite of all authors except Nicol!

*Ground between Druim-an-tenigh and the sections on Camas-an-Duin.*—The overthrown quartzite at the south end of Druim-an-tenigh can be traced continuously across the opening of the Arnaboll valley to the remarkable sections next to be described. The rock (Annelidian) is very well seen overhanging the road, dipping E.S.E. at  $50^{\circ}$ . As these outcrops are so conspicuous, and the beds appear so clearly to pass under the gneiss close at hand to the east, a hasty inspection would naturally lead to the Murchisonian conclusion. Nicol, however, held that the beds were reversed, grounding his opinion on the fact that "the openings of the Annelid-tubes and the ripple-marks, which are regularly found on the upper surfaces of the beds, are here on the lower faces." But as the marks on the lower surface of a bed are a facsimile of those on the upper surface of the bed in contact, it is not surprising that this evidence has not been held to be convincing. I have studied the rock with this test in view; but I could never find it to be of any service, the upper face of a bed presenting the marks sometimes in relief, sometimes in depressions.

*Sections (three) on Camas-an-Duin* (fig. 8).—These sections are even more satisfactory than that described at Druim-an-tenigh, since they display the Assynt series complete in all its members\*, and the overthrown eastern limb of the fold is brought into direct relation with the undisturbed western side.

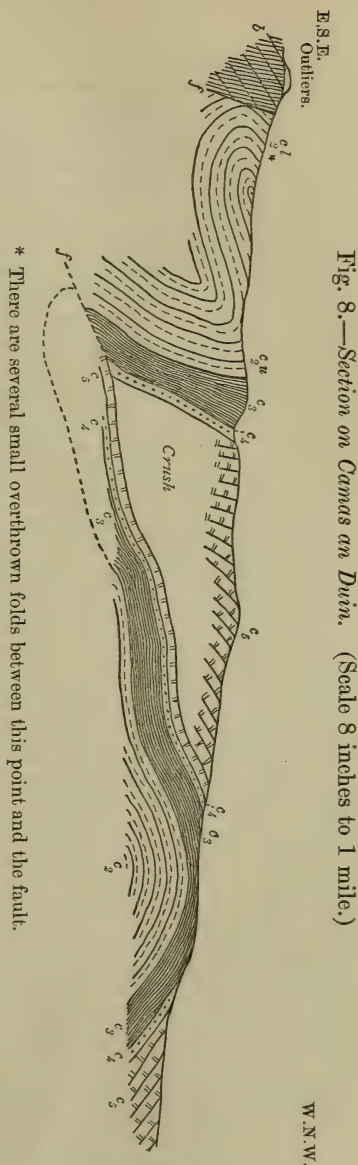
The southern margin of the Bay of Camas-an-Duin runs E. and W.; and the rocks are clearly exposed along the whole distance (1) at the shore-level, (2) along the road, (3) along the ridge to the south.

Commencing the *shore-section* at the little bay east of the Pictish Tower, we first identify the Annelidian Quartzite, and, by climbing up to the road, connect it with the overthrown quartzite just described. The dip, which at the road is  $50^{\circ}$ , rises towards the shore; and at about high-water mark it has become vertical. Then the beds begin to dip to W.N.W., the angle falling gradually to  $60^{\circ}$ . Here the strike curves round, so that the dip changes to W. and W.S.W., the strike corresponding with the last dip being maintained through the section. The dips now fall to  $30^{\circ}$ – $20^{\circ}$ . At the little

\* Except, of course, the Torridon, which does not occur east of Durness.

bay the rock is covered by sand for 120 yards, the only gap in the entire section; and this is really filled in a little higher up at the road-level. This sand must mask a slight fault and a syncline; for on its western margin we come to higher beds with an opposite dip. The first of these is the base of the Dolomite, dipping easterly at  $25^{\circ}$ . This rock is underlain at the Pictish Tower by the *Salterella*-grit, with fossils, followed in regular order by the Brown Flags and Annelidian Quartzite, the basset edges of the strata cropping out regularly from E. to W. Then the Quartzite becomes horizontal, and further on dips south-westerly, and is overlain in normal sequence by the Brown Flags (50-60 ft.), *Salterella*-grit (15 ft.), and Dolomite. The last-named is in full force, dipping steadily to the S.W., its lower (dark) and upper (white) members being as completely exposed as at Inchnadamff. West of the Pictish Tower, the Assynt series is thus seen to lie in a broad low arch, and there can be no question that the beds are uninverted.

Coming back to the east end of this section, we observe a fact which, for the sake of simplicity, I omitted in my first description. Resting on the Dolomite at the little bay is quartzite underlain by flags, dipping in the same direction as the Dolomite, but at a higher angle ( $50^{\circ}$ - $60^{\circ}$ ), so that the edges of the upper beds abut obliquely onto the bed-surfaces of the Dolomite. We ascertain by further study that these overlying rocks belong to the over-



\* There are several small overthrown folds between this point and the fault.

thrown side of the syncline ; so that they have been broken off and pushed to the west onto the Dolomite. The whole of the uninverted dolomite is obviously crushed out, except the few feet west of the little bay.

The *road-section*, at a level which rises from 60 ft. on the east to 140 ft. on the west, confirms and illustrates the last. The overthrown Annelidian Quartzite at the east end is contorted for a few feet, and is then succeeded by Brown Flags and *Salterella*-grit in nearly vertical beds. These are the strata which abut downwards onto the Dolomite. We then pass an interval of 130 paces occupied by *débris*, obviously masking the centre of the crush. Then we reach the anticline. Being at a higher level, we are chiefly in the *Salterella*-grit and Dolomite ; but at the west end we come onto the Flags, where they begin to bend to the south-west. The arch is more complicated than at the shore, the beds being puckered into two or three subsidiary curves. This is what we should expect from the closer proximity of the strata to the centre of the fold. The facts seen at the east end of this and the last section indicate that the folding-back is complicated by a reversed fault.

It will be convenient to take the ridge-section from W. to E. The ground rises from 140 ft. to about 600 ft. Leaving the road, we pass over dolomite dipping easterly, forming the eastern side of the arch and, of course, the western side of the fold. Higher up the dip rises, reaches the vertical, then changes to westerly at  $80^{\circ}$ . We are here apparently in the focus of the crush. Close by to the east (350 ft.) is a slight hollow ; and beyond it are the *Salterella*-grit, Brown Flags, and Annelidian Quartzite in regular sequence. The beds vary between an easterly dip at  $80^{\circ}$  and the vertical. This succession is precisely the same in lithology and thickness of beds as the arch-like section on the shore, but *in reversed order*, and it clearly constitutes the eastern limb of the synclinal fold. The Seamy Quartzite is found underlying the Annelidian higher up the hill. Following these quartzites along the strike to the north, we find they are continuous with the overthrown quartzite of Druim-an-tenigh ; so that the overthrow is proved both by actual observation of the gradual change of dip and by the reversed order of the succession.

This folding-back of the Quartzite and associated beds is seen very clearly all along the ridge from the Arnaboll valley to the line of the present section. Leaving the Eastern Gneiss, and descending the slope to the loch, we everywhere find that the quartzite, after a few sharp overthrown contortions, bends over to the west, and plunges down in vertical sheets, which, as we follow them downwards, gradually bend into the hill, so as to present an overhanging surface to the west.

These sections render intelligible the otherwise obscure ground between Druim-an-tenigh and Heilem Ferry. The peninsula at the ferry is composed of the Dolomite, dipping at a low angle to E.S.E., as if it would pass below the quartzite of Druim-an-tenigh. There is no reasonable doubt that this dolomite is continuous with the



dolomite of Camas-an-Duin, the strikes passing below the waters of the bay; and we know that the quartzite of Druim-an-tenigh is on the strike of the quartzite of the ridge above Camas-an-Duin. The northern section differs only in the apparent absence of the Brown Flags and *Salterella*-grit. There is, however, a considerable breadth of covered ground at the Heilem isthmus; and as the Flags and associated beds reappear on the strike further north, it is reasonable to infer that they are present in the isthmus beneath the superficial deposits. It is, however, possible that they may, in part at least, have been crushed or faulted out.

*Section in the Ravine above the Free Church.*—Following the dark Dolomite at the west end of the Camas-an-Duin section along the loch to the south, we find it overlain by the white variety, as in Assynt. The dip gradually sinks to the horizontal. Then there is sudden contortion and crush, and the dip changes to E.S.E., the same inclination being continued as far as the Erriboll ferry. Here I turned up the slope to the south-east, which is occupied by dolomite up to about 400 ft. It is seen dipping south-easterly at a moderate angle, and is, in the ravine above the church, overlain by fossiliferous *Salterella*-quartzite and grit, succeeded by the Flags (50 ft.) and the Annelidian Quartzite. The last is not more than 30 or 40 feet thick; and as it is broken and squeezed, there is no doubt that the Seamy Quartzite is faulted out against the Caledonian.

A little further to the south the folding-back of the Dolomite is very clearly seen. At first it dips easterly at a low angle; then, within a few yards, it is bent right up to the vertical, and thrown a little over, the *Salterella*-grit, Brown Flags, and Quartzite cropping out on the eastern side in regular sequence.

*Section above Erriboll House.*—The Dolomite, with an easterly dip, occupies the lower slopes from the loch upwards. It is overlain regularly by inverted *Salterella*-grit and quartzite, Brown Flags, and Quartzite, precisely as in the last section.

The so-called "Upper Limestone" comes in here between the Quartzite (inverted) and the gneiss of the Hope series. It is a mass of dolomite about 100 yds. long and 50 ft. thick. The gneiss, where it comes down to the Quartzite at each end, is contorted. These facts strongly suggest that this mass is merely a wedge of dolomite let down into the fault between quartzite and gneiss.

It would be superfluous to multiply sections in this area. The facts described are seen, with immaterial variations, wherever the rocks are clearly exposed. Having visited the district in two successive years, and traversed the ground over and over again, I can unhesitatingly affirm that all along the steep slopes which overlook the eastern side of Loch Erriboll between the north end of Druim-an-tenigh and the road to Altnaharra, a distance of nearly three miles on the strike, the members of the Assynt series, dipping easterly in inverted order, are bent back upon the same series dipping in the same direction and uninverted.

*Section at Craig-na-faolin.*—I have not examined the rocks on the strike to the south-west of the Altnaharra road; indeed the ground

is too much covered in to promise good results ; but we come again to the Assynt series in the prominent peak of Craig-na-faolin (934 ft.), which overhangs the south end of the loch. The upper half of the western escarpment is formed of Arnaboll gneiss, very hornblendic, about 300 ft. thick, passing up into gneiss of the ordinary Hope type. Dipping to the E.S.E., below the gneiss is the Annelidian Quartzite. A little further to the south the quartzite opens out on the strike, and Brown Flags come in between two bands of it. This is no case of thinning-out ; for the flags appear suddenly, and, instead of lying conformably with the quartzite, they are squeezed into a double fold like an upright letter **S** very broad for its height. The quartzite both above and below the flags is full of the worm-burrows. The section is not very clear ; but the facts, so far as they go, harmonize with our previous sections. The Quartzite, folded back upon itself, has caught a mass of the Flags and squeezed it into complex folds.

*Ground between Ben Arnaboll and Ben Heilem.*—North of the road from Heilem to Hope Ferry, and west of the Hope river, the rocks are all of the Assynt series. Quartzite, flags, and dolomite occur over and over again and in varied order, as if we had half a dozen similar successions thrown pell-mell together. I gave some study to the area, but concluded that, after the clear sections further south, it would not be a profitable use of time to attempt to unravel the confused tangle of faults, folds, and overthrows.

*Ground between Hope Ferry and Whitten Head.*—The river Hope forms the eastern boundary of the Assynt rocks as far north as its mouth ; but at this point the Quartzite crosses over to the north-east, and usually occupies the shore right along to Whitten Head, nearly six miles north of the ferry.

Where the Quartzite first appears, north of Inverhope, it apparently dips easterly under Arnaboll gneiss. The uppermost beds are of the seamy type, while the underlying strata at the shore are full of worm-holes. Hence there would seem to be an inversion, as in the southern localities.

A mile further north, in Cnoc-na-goar, the quartzite (which dips to the E., as if below the gneiss) is the lower band. Following it down to the shore-cliffs, we find the dip becomes progressively lower ; and just at the sea-level the beds roll over to the W., forming an anticline. At least this was the appearance from the top of the precipice to the south ; but the nature of the ground prevented a close examination. The same cause rendered it impossible for me to ascertain the intimate structure of the rock ; but the beds are apparently on the strike of the Annelidian Quartzite near Inverhope.

Two miles further north, near Fresgill, the Annelidian Quartzite occupies the shore, dipping easterly at a low angle. Large blocks of the Brown Flags are scattered about ; and, as they are unrounded, they cannot have travelled far. There are no other signs of this rock, so far I know, in the locality, or, indeed, anywhere north of Hope ferry ; so that perhaps it would be hardly rash to suggest that the

Flags may crop out low down on the shore, or under water, from beneath the Quartzite, and that the fragments have been thrown up by the tremendous waves which operate with such energy along this exposed coast.

At Whitten Head the rock nearest the Caledonian is the Seamy Quartzite. Fragments of the Annelidian variety are found lying about; but these towering precipices, rising absolutely vertical for nearly 500 feet, forbid close investigation, though a good cragsman might perhaps meet with some success. Something more might also be done with boats; but so heavy is the swell on these stormy shores that little could be effected, save in exceptionally calm weather, such as rarely occurs in the district.

The region north of Hope Ferry is thus seen to confirm the clearer sections further south, the upper division of the Quartzite being regularly overlain by the lower.

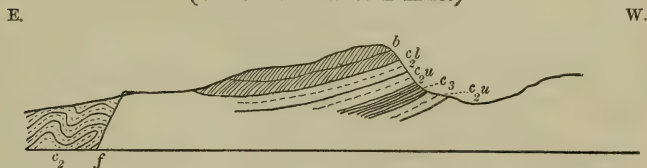
I claim, then, to have proved that the Assynt series is folded back upon itself for a distance of several miles south of Heilem, and to have shown it to be highly probable that the inversion occurs the entire distance from Craig-na-faolin to Whitten Head, a distance of nearly 12 miles.

*C. The Caledonian Gneiss brought over the inverted Assynt Series by Earth-movements.*

*Structure of Ben Arnaboll (756 ft.)* (figs. 9 and 10).—Good sections are exposed along the dip (W. to E.) and the strike (N. to S.)—the former in the cliff south of the road from Heilem to Hope ferry, the latter in the precipitous escarpment overhanging the valley which separates the hill from Druim-an-tigh.

The *dip-section* (fig. 9) represents the gneiss clearly overlying the Quartzite\* for a breadth of over a quarter of a mile, the two series

Fig. 9.—Section of the northern side of Ben Arnaboll.  
(Scale 4 inches to 1 mile.)



being at first sight apparently conformable, dipping to S.S.E. A close examination, however, shows that the conformity is not perfect. In one place the gneiss dips down onto the quartzite at a higher angle, and other beds of gneiss come into the angle between the two. At another spot, further to the east, the gneiss does not keep

\* The band of quartzite in contact with the gneiss is slightly altered (no. 99, p. 418).



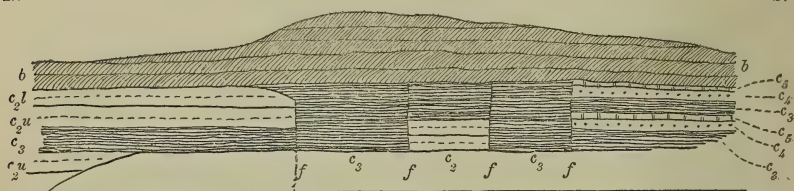
to the same bed of quartzite, but overlaps the edges of several beds within a few yards. We are not, however, left to such minute points of criticism. Here, again, our knowledge of the Assynt succession solves the difficulty. The beds of quartzite in contact with the gneiss are of the *Seamy* type; and lower down the slope the upper (*Annelidian*) division comes in. Further west, at the corner where the cliff curves abruptly round to the south, the Brown Flags appear below the Annelidian; and below the flags, at the base of the escarpment, the Annelidian comes in again. This structure is similar to the inverted syncline on Camas-an-Duin, the *Salterella*-grit and Dolomite being absent from the centre of the fold, as in Craig-na-faolin.

The same relations are continued for some distance along the *strike-section* (fig. 10). The ground now rising towards the south,

Fig. 10.—*Strike-Section of the western escarpment of Ben Arnaboll.*  
(Scale 8 inches to 1 mile.)

N.

S.



the Quartzite under the flags is soon hidden, and the flags occupy the base of the cliff. Then suddenly the Quartzite (about 200 ft. thick) above the Flags disappears, and the latter form the whole of the scarp below the gneiss, the Quartzite and Flags being separated by a vertical fault, except at the top, where the Flags send a narrow wedge to the north, between the Quartzite and the gneiss. Further south the place of the Flags is taken by confused masses of quartzite and flags; but just above the little loch the succession is clear.

The cliff at this spot from its foot to the base of the gneiss is 200 feet high. It displays an exact repetition of the Assynt series from the bottom of the Flags to the lower part of the Dolomite. Quartzite lies at the foot of the scarp. Ascending over the Flags, in which we can make out three horizons, at 60 feet we reach the *Salterella*-grit and Quartzite, and at 90 feet we come to the base of 10 ft. of dolomite. At 100 feet the Flags rest on the Dolomite, the lower rock dipping E.S.E. at  $40^\circ$ , and the Flags at  $30^\circ$ , the beds of dolomite being curved outwards as if by the pressure of the overlying flags. The second 100 feet is the lower succession repeated, even to the 10 feet of dolomite. It will be observed that in this section the rocks are not inverted.

The faulting here is not normal; for the repeated series rests on the lower one in a steep cliff, but is clearly reversed. The westerly push of the repeated beds tends to confirm my explanation of the



overlie of the gneiss. The same force which doubled the Assynt series back upon itself could also have brought the gneiss over the Assynt series.

These sections not only add to the proof of inversion and overthrust, they show that, even putting inversion on one side, the alleged evidence for a conformable succession breaks down. The gneiss in the western escarpment forms the upper part of the cliff continuously from north to south, lying in apparently regular beds. But the underlying rocks are a confused mass of fragments, some right side up, others upside down, but neither the normal nor the inverted blocks being continuous for many hundred feet. This enormous crushing probably took place while the Assynt series was being folded back by the thrust of the Caledonian.

*Junction South of the Arnaboll Valley.*—At the opening of this glen on the south side, the Arnaboll gneiss rises in several small humps, from which the Quartzite dips in various directions, as if tilted up by the upheaval of the gneiss. The chief junction is well seen at the top of the slope, a little notch separating the two groups. Some schisty, rather rotten beds are in contact with the Quartzite; and the Caledonian forms a low scarp at the east side of the gap, which is but a few yards wide. The gneiss is of a reddish colour, and it is associated with some grey felspathic schist, the whole being penetrated by granite veins. The dip of the gneiss is E.S.E. at  $60^{\circ}$ , while the Quartzite dips W.N.W. at  $70^{\circ}$ – $80^{\circ}$ . The quartzite is the lowest of the group, the base being a thin band of conglomerate like the basement seam in Glen Coul, and the grit bed occurring in its usual place about 10 feet above. After some sharp contortion, the beds plunge over to the west, as already described. The discordance between the gneiss and the Quartzite is thus seen to be very well marked.

Following the basement quartzite on the strike to the south, we find it gradually rises to the vertical, and then is folded back so as seemingly to dip below the Caledonian, the conglomerate being still in contact, and the grit-bed about 10 feet *below* the gneiss. The process by which apparent conformity is produced is thus very easily observed. This overthrow is in the lowest quartzite, and is quite irrespective of the great overthrown fold further west. Several other small contortions also occur in the quartzite before it takes its final plunge down to the loch.

Further to the south the lowest quartzite is crushed out, the Annelidian Quartzite, and that only in part, being in contact with the Caledonian.

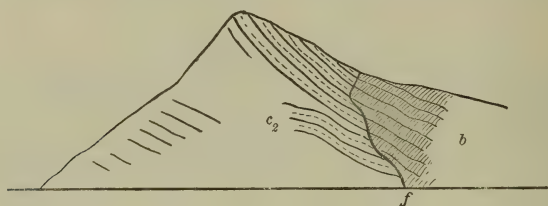
Taking the same line, but turning our attention to the gneiss, we observe still more striking proofs of want of conformity. The Quartzite strikes steadily to S.S.W., while the strike of the gneiss is between S.W. and W.S.W. The Quartzite is thus brought against higher and higher beds of gneiss, till finally the Arnaboll type contracts to a narrow wedge and disappears, and the Quartzite comes up to the Hope series, with which it remains in contact for miles to the south.

We have thus a twofold discordance. From north to south gneiss is brought against higher beds of quartzite, and quartzite is brought against higher beds of gneiss.

*Junction North of Hope Ferry.*—The high ground above the ferry is occupied by gneiss on the strike of the gneiss on Ben Arnaboll; and this rock forms the crags overhanging the Hope river to near Inverhope, where the Quartzite comes in. In the cliffs to the north-east of Inverhope the gneiss is sometimes very hornblendic, sometimes passing into hornblende-schist. Here there is also a felspathic schist, somewhat like a banded hälleflinta. No actual junction is seen, but the Arnaboll gneiss apparently overlies the inverted Quartzite.

We now come to the striking and instructive section exposed in Whitten Head (fig. 11). In these tremendous cliffs, the junction

Fig. 11.—*Section at Whitten Head.* (Scale 1 inch to about 500 feet.)  
W. E.



of the two groups is exposed as clearly as in a diagram, the snow-white quartzite forming a vivid contrast to the gneiss, with its stripes of red and dark-green colours. The line of separation is an irregular fracture, which first inclines for a short distance towards the west, then turning at an obtuse angle it fades in an easterly direction down to the base of the precipice. The hade being to the upthrow, the fault is of course reversed. Both series dip easterly at about the same angle, the result being that, at some parts of the fault, the gneiss rests conformably upon quartzite. Had the rocks been exposed only upon horizontal surfaces, the two groups would have seemed perfectly conformable. This section thus shows how those appearances have sometimes been caused which have led observers to infer a "clear ascending series."

North of the Head are two remarkable pinnacles of quartzite rising like gigantic columns out of the sea. Nearer the cliffs is a third stack, into which, according to Murchison, "a shaft of felspar-rock" has been intruded. My reading of the facts is widely different. The pinnacle is a mass of quartzite dipping gently to the west, and resting upon a base of red and dark-green gneiss. There may be granite veins in the gneiss (the distance from which the rock was observed was too great for the determination of this point); but certainly no intrusive rock passed up into the quartzite, the basement beds being unbroken and nearly horizontal. This superposition of the quartzite on gneiss is on the west side of the

fault, which here runs along the cliff. I could not at the distance determine whether the gneiss was Hebridean or Caledonian, but the colour was that of the latter.

*Ground between Druim-an-tenigh and Ben Arnaboll.*—Between the inverted synclines on the western slopes of these parallel ridges the rocks are very broken. North of the little loch in the intervening valley, the *Salterella*-zone with overlying dolomite was repeated more than once. The strike of these beds, when continued to the north, diverged more and more from the strike of the Assynt rocks in the escarpment; and just above Loch Craggie a mass of Annelidian Quartzite, with strike at right angles to the beds on each side, came in. It really seemed as if this were a wedge thrust in from the north, and that it had forced apart the faulted strips between which it had been intruded.

Very striking evidence of lateral pressure is seen in this quartzite. The worm-tubes, originally vertical, are all strongly bent towards the west. The contortion is even more marked than in the tubes of the quartzite at the Stack of Glen Coul. As this mass is out of place, the side pressure must have been subsequent to the faulting. In a small hill to the west the same phenomenon is repeated. The next ridge to the west is composed of the Flags, which are bent in different directions and terribly broken, fragments of quartzite being also thrust in amongst them. This ground has been described to supply corroborative evidence of lateral thrust and dislocation.

#### D. *Outliers of the Assynt Series on the Caledonian.*

Nicol, in his Camas-an-Duin section\*, represents an outlying fragment of quartzite on the top of his "intrusive granulite." As the latter rock is certainly a gneiss; the quartzite is to be regarded as a true outlier. I have detected two other outlying patches on the plateau between the Arnaboll valley and the point where the quartzite comes up to the Hope gneiss, so that they all rest upon the Arnaboll group, which here forms lower ground than the Hope rocks. One of these outliers (see fig. 8, p. 399) lies a little north of the point where the Arnaboll gneiss; disappears, and a second a short distance on the strike to the north of the first. They are not far to the east from the junction between quartzite and gneiss, the latter in both cases clearly intervening between them and the chief mass to the west. They are composed of the basement beds of the quartzite, seamy and gritty. The dip is easterly at a low angle, the rock being somewhat disturbed, as if exposed to subsequent compression.

A third mass of quartzite forms a boss on the top of the southern slope of the Arnaboll valley at its eastern end. The strata plunge about at various angles in almost every direction. On the north side, the lowest bed, the conglomerate, dips N. at Arnaboll, gneiss also dipping N., the usual dip of the gneiss in this locality being S.S.E. On the western face of the knoll the quartzite dips S.E., as if away from a mass of gneiss which rises on the west.

\* Quart. Journ. Geol. Soc. 1860, vol. xvi. p. 88.

The significance of these facts is obvious. As the quartzite in these outliers rests unconformably upon the Caledonian, the latter must be the older series.

Prof. Nicol, whose identification of the gneiss as "intrusive granulite" precluded him from the use of this argument, described what he considered an outlier of the younger rocks at Cnoc Craggie, near Tongue. With his interpretation I am unable to agree. The hill is a mass of breccia, the fragments being chiefly composed of the flaggy gneiss. The rock bears no resemblance to the Torridon Sandstone, to which Nicol referred it. The quartzite, which he supposed to overlie at the southern end, refused to disclose itself, though I searched every yard of the ground. The only stratified rock visible was the ordinary thin-bedded gneiss, which towards the hill became brecciated and appeared to pass into the breccia. A reddish granite is intruded at this point.

#### E. *Granite not intrusive in the Assynt Series.*

If the gneiss normally overlies the Assynt rocks, we ought sometimes to find granite intrusive in the latter. Yet although the gneiss in the Erriboll area is, as Murchison stated, "riddled" with granite, the granite never appears in the adjoining quartzite. Murchison, indeed, describes what he considered an example of such intrusion in the north-and-south ridge east of Heilem\*. My examination of the rocks did not lead to the same conclusion. In the centre of the ridge, I found not only granite but a narrow wedge of gneiss, which certainly could not be intrusive in the ordinary sense. I observed, moreover, that the quartzite, flags, and dolomite on each side were tilted up by the interior mass, whereas the granite in the gneiss of this area does not produce this effect. On the east side, dolomite dipped away at a moderate angle; and on the west, the flags, which in one place dipped away from the ridge at 80°, were seen, when traced down the steep slope, to rise to the vertical, and then to fall over to the west, so as to dip into the hill. The so-called "intrusive granite" is, then, a linear wedge of gneiss with granite in it, thrust up amongst the overlying Assynt series, which, on the west side, it actually overthrows. The ridge is precisely on the geographical strike of Druim-an-tenigh, and the overthrow is similar.

### III. IGNEOUS ROCKS.

The result of my work has been to considerably reduce the quantity of igneous rock supposed to exist in the North-western Highlands. Omitting ordinary dykes and small masses of dolerite and felsite, the following deserve notice.

\* Called "Drumtungi" in his section (Quart. Journ. Geol. Soc. 1859, vol. xv. p. 234). This name, or "Druim-an-tenigh," is, however, given to the ridge lying to the south, described by me above.



### 1. *Loch-Ailsh Group.*

The prevailing rock in this mass is reddish in colour, of a granitoid texture, and mainly composed of quartz and felspar. Prof. Bonney describes it (No. 109, p. 420) as "a kind of syenite;" but hornblende is certainly not a very conspicuous constituent. An exceptional variety, garnetiferous (No. 72, p. 420), occurs east of Loch Borrolan, on the slope north of the road.

These rocks form the ranges of hills which strikes S.E. and N.W., between the gap south of Loch Ailsh and Ledmore, and culminates in Cnoc-na-Strone, above Ledmore. From the hill west of the gap, the igneous rock turns to the N.E., and appears here and there through the quartzite of Loch Ailsh and the south-eastern slopes of Scounan More. Growing more conspicuous, it rises into Scounan Beg, a prominent hump, recognizable at a distance by its coppery colour. The igneous rock is here in immediate contact with the old gneiss of Scounan More, and is intrusive in it in a small mass 100 yards to the west of Scounan Beg. Vertical jointing is very conspicuous in the latter hill. The syenite is continued across the Oykel, being well exposed in the river-bed for a breadth of nearly two miles, its eastern boundary passing a little north of Kinloch Ailsh. Its north-eastern extremity forms a reddish mass, the counterpart, on the opposite side of the river, of Scounan Beg. A little east of this point it comes up to the eastern gneiss, cutting out the marble. All other conspicuous elevations which have been marked as "igneous" in this area are Hebridean.

### 2. *Igneous Rock of the Quartzite.*

I have already referred to the occurrence of this rock in the Quartzite as a useful indication of a certain horizon. On the south-west side of Loch Assynt the "porphyry" contains very large crystals of felspar. This interesting variety has been described by Prof. Heddle\*. Generally the igneous rock is more compact, and might be described as a porphyritic felsite. It is frequently interbedded, but is probably not contemporaneous. Diorite (No. 71, p. 419) also frequently occurs at the same horizon.

### 3. *Granite of Durness and Loch Erriboll.*

The granite of Loch Erriboll is mainly composed of quartz and a brick-red felspar, with a peculiar glassy cleavage, which is characteristic of the granite east of the loch. The granite intrusive in the Hebridean of Durness is of similar composition; but the distinctive cleavage is absent. Veins are much more abundant in the Arnaboll gneiss than in the Hebridean of this district. They rarely appear in the Hope series in this area; but I noticed in Craig-na-faolin, where the Arnaboll passes conformably up into the higher group, that some veins penetrated the lower beds of the latter.

\* Mineral. Mag. Aug. 1881, p. 233.

## IV. SUMMARY OF RESULTS.

1. The Assynt series has been doubled back upon itself in a compressed synclinal fold along Loch Erriboll, so that the Quartzite is brought up over the Dolomite. In Assynt, also, the quartzo-dolomitic group has been folded back, though less conspicuously. On Loch Broom, the Dolomite does not come into contact with the Eastern Gneiss at all, but is separated from it by older faulted rocks.

2. The Assynt series and the Eastern Gneiss in the three areas described display a discordant strike and dip. On Loch Broom the dip of the former is north-easterly, that of the latter south-easterly. In Assynt, where the rocks are in contact, as at Glen Coul, the dip of the gneiss is north-easterly, that of the quartzite south-easterly. On Loch Erriboll\* the discordance is double, both the gneiss and quartzite, taking them from north to south, coming respectively into contact with higher and higher beds of the other group.

3. The "Igneous Rock" of some authors, "Logan Rock" of Dr. Heddle, is usually the Hebridean gneiss. On Loch Broom it is brought into contact with almost every member of the Assynt series in turn, and slightly overlies them. In Assynt this gneiss, sometimes accompanied by the Torridon Sandstone, is thrown over onto the Assynt series, the overthrow increasing in breadth northwards, so that on Loch Glen Coul it is more than a mile wide. The "intrusive granulite" of Nicol is the Arnaboll gneiss overlying the Quartzite and associated rock.

4. The determination of the last point materially adds to my argument, the patches of quartzite resting on the "granulite" being really outliers of the Assynt series lying unconformably on the Arnaboll gneiss. The absence of granite veins in the Assynt series points in the same direction.

5. The "Upper Quartzite" of authors is, in Assynt, the quartzite under the dolomite repeated east of the fault, which brings up the Hebridean. On Loch Erriboll it is the same quartzite repeated on the eastern side of the great synclinal fold.

6. The "Upper Limestone" is, on Loch Ailsh, marble and crystalline dolomite in the Caledonian series. Near the Stack of Glen Coul it is the Assynt dolomite repeated east of the Hebridean fault. Above Erriboll House it is a faulted fragment of the dolomite appearing east of the inverted quartzite.

7. The Eastern Gneiss, though actually overlying the Assynt series in some localities, has been brought into this abnormal position by earth-movements subsequent to the deposition of the latter, and is of greater antiquity.

8. The Eastern Gneiss is widely separated in age from the Hebridean.

\* If the Arnaboll series should, contrary to my belief, turn out to be the older gneiss, my case would be even strengthened; for then we should have the Quartzite along the same line resting against both Hebridean and Caledonian, and, according to the old view, passing conformably beneath both.

## V. GENERAL CONSIDERATIONS.

If the Eastern Gneiss is older than the Assynt series, it must be Archæan. Whether or not the Assynt dolomite is the equivalent of the Durness limestone, it is not of less antiquity; so that the gneiss is at once proved to be at least Pre-Ordovician. But it can hardly be Cambrian, for we have no evidence in the British Isles of any metamorphic rocks of that age.

But Murchison extended his induction to nearly all the metamorphic rocks of Scotland outside of the Hebridean area; and Harkness, supported by Murchison, applied it to the schistose rocks of Ireland. These wide-reaching conclusions, should my evidence be accepted, must also fall to the ground.

It remains to inquire to which of the Archæan groups must the Eastern Gneiss be referred. Dr. Sterry Hunt claims it for his *Montalban* group. This view can, I presume, be affirmed or rejected by no one; and our consideration of it must be postponed till our knowledge of these old rocks is riper. There are some lithological resemblances between the Eastern Gneiss and the older of the Anglesey Archæan series,—between, for example, the flaggy quartzose gneiss and the green chloritic schists of both areas. If we are able hereafter to connect the two formations, it will probably be done by taking Ireland as a stepping-stone. At present it appears to me the safest course to adopt a local description; and, from the wide extent of the gneiss throughout the ancient Caledonia, I have proposed the term “Caledonian.”

I do not assume that all the newer gneissic rocks of Scotland belong to this series. Dr. Hicks claims to have identified several groups south of Loch Broom; but I am unable to express an opinion of his work from personal observation.

My conclusions will remove a theoretical difficulty which has doubtless burdened the minds of many geologists. It has been regarded as highly perplexing that comparatively unaltered rocks should be overlain by a metamorphic series. How could metamorphism have taken place in an upper series without affecting the lower, except on some principle of selective change? But this explanation cannot here apply, since parts of the Assynt series are composed of materials which could be readily decomposed and re-composed.

I have more than once expressed the opinion that, so far as England and Wales are concerned, all areas which had undergone regional metamorphism were Archæan. These views seemed to me to be confirmed by my study of the rocks of Leinster. But a much more extensive territory must now be annexed to the Archæan kingdom, and we seem to be approaching the induction that all British metamorphic districts are included within its boundaries. This will greatly add to the importance and interest of our Archæan studies.

It will perhaps assist in anticipating certain objections if I describe the sequence of events which, in my view, has taken place in North-western Scotland.

1. The Caledonian was laid down unconformably upon the Hebridean.

2. The Caledonian was faulted down to the east along a S.S.W. line, and was subsequently denuded from the upcast side.

3. The Assynt series was deposited on the Hebridean; and being derived from land to the west, it thinned out eastwards, only the attenuated extension of its strata passing beyond the fault to the Caledonian.

4. The motion of the Caledonian was reversed, and it was upheaved along the old line of fault, breaking off the overlying quartzite and dolomite along the same line, parallel faults being formed near it to the west. By powerful lateral thrust from the east, the Caledonian was forced up beyond the fault, so as to double back the Assynt rocks and to overlie them for some distance. At the same time a parallel slice of Hebridean lying to the west was, in like manner, thrown over onto the quartzite and dolomite.

5. The Assynt rocks east of the great fault were denuded, leaving only a few scanty patches of quartzite.

## VI. REPLY TO OBJECTIONS.

Perhaps the most serious difficulty is found in the fact that when the Assynt series reaches the Caledonian, the former suddenly disappears, except in the insignificant patches east of Loch Erriboll. These, if true outliers, of which I entertain no doubt, at once fix the superior antiquity of the gneiss, even in the absence of all other proof; but I think it can be shown that, irrespective of these outliers, the difficulty indicated is not so great as may at first appear.

I may point out that an adherent of the Murchisonian school making this objection would expose himself to an effective *tu quoque* retort. If the Eastern Gneiss once overlay the Durness and Assynt limestones, why are there no outliers of the gneiss upon the limestone? If so tough and enduring a rock as the quartzose schist of the gneiss series once extended for miles to the west over the limestone, it is incredible that every scrap should have been swept out of their synclinal folds. Some of these folds were closely pressed together at probably the close of the Ordovician epoch; yet they do not enclose the merest fragment of the immense thickness of gneiss which *ex hypothesi* conformably overlay.

The objection suggested may be mitigated by the following considerations:—

(1) The Assynt series thins out towards the east. The Torridon Sandstone rarely reaches as far as the Caledonian; in some places, as on Loch Glen Coul, it disappears at two or three miles west of it. The upper members of the series are also attenuated in the same direction. In Glen Coul, the quartzite, flags, and dolomite do not exceed 250 feet. Even if the thinness of the dolomite be due to faulting, this cause cannot account for the insignificance of the flags, which are conformably interbedded between the quartzite and the dolomite. In Ben More of Assynt and Ben Arnaboll, the



dolomite, which is covered by overthrown gneiss, is, in the former, less than 30 feet, and in the latter not more than 10 feet in thickness. I cannot, however, positively assert that this thinning of the dolomite is not due to faulting.

(2) The denudation along the line of the great dislocation has been very great. The outliers of quartzite which lie upon the Arnaboll gneiss are the base of the series, and not over 30 feet thick; but within a mile to the west the Quartzite and Dolomite are in full force. The Dolomite and Flags have been preserved within the synclinal fold; but as we ascend the ridge we find the different groups cleared away one after the other till, at the summit plateau, both in the outliers and the main mass we have only the basement beds. In Assynt, also, strata higher than the Quartzite are rarely found on the prominent ground; and their occurrence at lower levels is due to favourable circumstances, such as being enclosed in synclines, surrounded by durable strata, as in the Stronchrubie basin. Towards the Eastern Gneiss the Quartzite itself is usually partially thinned away, the lowest beds only remaining. Near Ullapool the evidence of excessive denudation is very clear. There are, near Loch Auchall, broad bands of faulted Torridon Sandstone intervening between the Caledonian and the upper members of the Assynt series. We know that this Torridon was once covered by 500 or 600 feet of quartzite, flags, and dolomite, which have been clean swept away.

That areas of dislocation should be subject to great denudation is only natural when we reflect that upheaval and depression tend to repeat themselves at successive epochs along lines of weakness. The chain of the Wrekin, for example, a mere wedge of the Archæan floor, thrust up at a fault, has been alternately rising and sinking since Cambrian times. In like manner the Caledonian at the faulted junction with the Assynt series has probably been elevated and depressed more than once since the Ordovician epoch. The alternation, then, of marine with subaerial action would be so effectual that the presence rather than the absence of fragments of a formation about 100 yards thick would be matter for surprise. This view is greatly strengthened by the present elevation of the Caledonian. All along its junction with the newer rocks on Erriboll, in Assynt, and near Ullapool, it forms high ground, frequently rising into lofty mountains. Either, therefore, the quartzite which once rested on it must have been raised up some 300 or 400 feet at least once, during which time the quartzite constituted the capping of the escarpment formed by the upthrow side of the fault, and would suffer the usual degradation of escarpments; or the gneiss had been carved into something like its present features before the Assynt epoch, in which case its superior elevation would account for the attenuation of the quartzite.

If still it should be contended that outliers of the quartzite upon the Caledonian ought on my hypothesis to be more extensive, I may call attention to the parallel case of the Penine fault. The great escarpment which overlooks the valley of the Eden along a line of 20 or 30 miles, is mainly composed of Carboniferous rocks, the

highest summit, Cross Fell (2900 feet), being capped by Coal-measures. The valley below is occupied by Permian and Triassic deposits, faulted down at the foot of the scarp. The average thickness of the Permian alone is estimated at between 3000 and 4000 feet; yet not a fragment of it remains east of the fault. If an extensive plateau has been swept clean of 3000 feet of sandstone since the Permian epoch, it is not surprising that another plateau should have been cleared of 300 feet of quartzite since the Ordovician period.

If it be objected that the stupendous inversions and overthrows which I have described are improbable, I have only to reply that such effects are not uncommon in disturbed districts, and are familiar to geologists. I will only call attention to a remarkable example, copied from A. von Heim by Dr. A. Geikie, in his new 'Text-Book of Geology,' p. 518. On the left of the section "schistose rocks, perhaps metamorphic Palæozoic formations," with white Jura conformably underlying, rest upon the upturned edges of highly contorted Eocene strata.

In the paper which I thus bring to a conclusion, I claim to have invented no new method of investigation. I have worked upon the recognized principles of our science, and they have been found sufficient for my purpose. I shall be rewarded for my labour, if I have succeeded in emphasizing the truth, that the only authority to be recognized by geologists is the authority of Nature herself.

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## APPENDIX.

*Notes on a series of Rocks from the North-west Highlands, collected by C. Callaway, Esq., D.Sc., F.G.S.* By Prof. T. G. BONNEY, M.A., F.R.S., Sec. G.S.

IN describing this interesting series of rocks I shall endeavour, as far as possible, to gather them into groups in order to save the repetition of details. A lengthy description will in most cases be unnecessary, because the majority of the specimens belong to types which have already been described with considerable fulness by Mr. T. Davies and myself.

The first group is a series of coarse, rather granitoid gneisses, generally admitted to be representatives of the Hebridean series. These rocks are rather coarsely crystalline in texture, generally not conspicuously foliated, containing a variable amount of hornblende or of black mica, but occasionally having a white mica as the third constituent.

Under the microscope, the minerals are well crystallized internally, but do not, as a rule, exhibit externally a definite crystalline form. Those ordinarily occurring are quartz, felspar, mica, and hornblende, with commonly some sphene and epidote, and, occasion-

ally, apatite. Some granules of magnetite, hæmatite, or, perhaps, ilmenite are usually present.

The quartz occurs as rounded to rather elongated grains of variable size, often grouped. Commonly, as seems to be usual in these very ancient rocks, they contain so many minute enclosures as to have a rather "dusty" aspect. Some of these may be microliths of various minerals (a micaceous one among them); but others are certainly cavities, not seldom very irregular in form. These frequently contain bubbles relatively as well as absolutely of very small size, which move freely.

The felspar occurs in grains, with outlines either rounded or somewhat irregular. A portion, no doubt, is orthoclase, but Carlsbad twinning does not appear to be common. Very characteristic microcline is almost always present in the slide, and is frequently common. Another triclinic felspar is also frequent, this exhibits repeated oscillatory twinning, and the laminae generally extinguish at small angles (commonly less than  $10^\circ$ ) with the twin plane, when it is coincident with a vibration-plane of one of the crossed Nicols. Hence most of it is probably albite or oligoclase.

The hornblende is usually green, dichroic, and shows characteristic cleavage. The black mica is frequently more or less replaced by a green secondary product allied to chlorite, as is common in ancient rocks. The white mica occurs in moderate-sized plates, exhibits a rather wavy cleavage, and gives bright colours with the two Nicols.

The sphene (or what I take for it, as the identification is not always certain) is not very clear or characteristic. The other minerals do not call for special remark.

#### *Hebridean Gneisses.*

In this Hebridean group I place the following specimens of Dr. Callaway's collection:—

62 (Durness). In this specimen some of the plagioclase extinguishes at angles too large for oligoclase or albite; there is a good deal of apatite; and we find, with a considerable quantity of most characteristic hornblende, a pale green mineral in rather irregular clusters, associated with earthy-locking granules. The cleavage in the cross sections is not very distinct, but the extinction-angle in longitudinal sections is often much too large for hornblende, so that I am induced to regard it as an abnormal form of augite—a mineral, so far as my experience goes, extremely rare in all rocks of this description.

64 (Ben Arnaboll, Loch Erriboll, p. 396) contains a considerable quantity of black mica. The structure of this rock is a little peculiar, and I could conceive it possible that it was an igneous rock crystallized under a definite pressure. I think, however, it is a true gneiss.

75 (Glen Coul, p. 384), a hornblendic gneiss, contains a good deal of a pale green mineral, which appears to be an alteration product after black mica.

76 (Eagle Rock, south-east spur, pp. 374, 381). This specimen contains very little quartz. The structure is rather obscured by crushing,

and some of the hornblende appears secondary. If the rock be metamorphic in the ordinary sense, it belongs to this group; but I have great doubts whether it is not a true igneous rock.

77 (Valley south of Ben Arnaboll, p. 396), hornblendic gneiss with some microcline; 78 (*ibidem*, p. 396), rather crushed, rather rich in microcline, containing little besides felspar and quartz.

79 (West of Cnoc Chaorinie, p. 388) rather rich in white mica, no hornblende or black mica.

80 (Craig Dhu, pp. 374, 378). Composition resembling 78, much crushed, with a little viridite infiltrated in the cracks; greatly resembles the so-called igneous rock near the fault in Glen Laggan described in my paper (Quart. Journ. Geol. Soc. vol. xxxvi. p. 93), and, like it, is certainly one of the granitoid gneisses of the Hebridean series.

81 (Burn of Calda, p. 378) contains, with some hornblende, a mineral resembling that described in 62, but more characteristically a diallage; part of it has been converted into uralite. Even diallage, so far as my experience goes, is rare in gneisses; though, looking at the mode of its occurrence in igneous rocks, one would not be surprised to find it. Some grains of structure generally similar are replaced by an earthy-looking rather serpentinous mineral. If this rock be metamorphic it is certainly Hebridean; but I feel doubts whether it may not be an igneous rock which has been deprived by local crushing of its most characteristic structures.

#### *Rocks probably crushed in situ.*

Several of the above rocks exhibit some indications of crushing and recementation; but in the group to which I now proceed this is very conspicuous, and sometimes has so much obscured the original structure that it is difficult to pronounce upon the true character of the rocks. In most cases, however, I feel tolerably certain that they belong to the Hebridean series. The cementing agent is chalcedonic quartz, but other minerals, as viridite, sericite (?), and iron-oxides are associated with it. The felspar is frequently greatly decomposed and replaced by various earthy-looking granular minerals, some of which may possibly be related to staurolite or andalusite. The percolation of water through the pulverized mass, while it favoured the deposition of quartz &c., would be likely to remove the alkaline constituents of the felspars. The deposition of micaceous or chloritic minerals on the surfaces of minute fracture under continuous pressure often gives the rock the macroscopic aspect of a dull-coloured normal mica-schist; but when it is examined microscopically, we see how superficial is this resemblance, and the true alliance of the rock with the ordinary gneisses is revealed. To this group belong 63 (2 miles S.S.E. Ullapool, pp. 364, 378), 73 (Dhuloch Beg Burn, 378, 381); 74 (2 miles S.S.E. Ullapool, pp. 364, 378) contains some calcite and dolomite (?). A secondary mineral has crystallized with it, which appears to be felspar, and the same borders some of the broken and decomposed original grains of that mineral.

83 (Balloch, Ben More), 84 (Burn of Calda), 85 (*ibidem*), 86 (*ibidem*) (p. 378). Though parts of the slides bear a most remarkable



resemblance to a true grit, I cannot help suspecting from others that we have here only a very exceptional case of local crushing of a Hebridean gneiss; the difficulty is increased by the matrix in which the fragments appear being darkened, in the case of the one which is most grit-like, by an iron-oxide.

87 (*ibidem*, p. 378). Seems to be a gneiss more or less crushed; parts of the slide are darkened as in the last; and a good proportion of the quartz has the aspect of being of secondary origin.

88 (Camaal Loch, p. 378). This, again, is a most puzzling rock, having a very clastic aspect; but I have very strong suspicions that it is only an exceptional specimen of one of the Hebridean gneisses (containing two kinds of mica).

89 (Calda Burn, p. 378), 90 (Dhuloch More Burn, p. 378). Though these slides present some peculiarities and differences of structure, I am disposed, though with hesitation, to place them in this group.

91 (Calda Burn, p. 378) also belongs here.

*Rocks retaining traces of a Clastic Origin.*

The rocks hitherto described do not appear to include specimens of the distinctly foliated gneisses and mica-schists, often garnetiferous, which I have collected on Ben Fyn and received from other localities\*, so that I pass on at once to a group most of which are evidently formed of detritus obtained from the series just described. Of these I shall not attempt to determine the definite geological position. While all of them give marked indications of alteration, this is insufficient to obscure the more conspicuous features of the original structure. Representatives of this group have been described by myself from the Torridon sandstone, quartzites, and "upper gneiss" (from its northern escarpment), near Loch Maree (*Quart. Journ. Geol. Soc.* vol. xxxvi. p. 98); so that it is needless here to enter much upon details.

92 (Dhuloch More Burn, pp. 361, 380.) Composed of subangular fragments chiefly from the Hebridean series; probably Torridon Sandstone.

93 (*ibidem*, p. 380). Fragments smaller and more angular.

94 (Coniveall, pp. 360, 379, 383). Fragmental and variable in structure from coarse to fine, derived mica, some fragments like bits of a vein of quartz or a minute quartzite, some epidote.

95 (Bealach Choinnich, p. 382) seems to be a rearranged Hebridean rock. The fragments are mostly rather angular, among them many of vein-quartz or the quartzose portion of a schist, felspar much decomposed, a good deal of a secondary green mineral (? chlorite). The rock appears to have been greatly compressed, as if nipped in a fault.

98 (Glen Coul, south side, p. 390). Chiefly quartz (fragmental) and sericite(?), evidently much compressed, as shown by the flattening-out of the grains. Probably not far in stratigraphic position from the quartzite group; perhaps rather above it.

\* These form the second group of the specimens which I have described in an appendix to the paper by Dr. Hicks published in the present volume, p. 141.

100 (Loch Ailsh, north end, p. 387). Minute grains of quartz with mica (fragmental), epidote, and fine granular matter, probably resulting from the decomposition of felspar. Does not appear to be very compressed.

101 (Cnoc Chaorinie, p. 387). A quartzite. The structure of this is rather peculiar; the recognizable fragments are interspersed in a quartzose ground-mass, of which at any rate a large part seems to be chalcidonic. Most of the larger fragments are, as it were, fringed with a deposit of microcrystalline quartz. The slide is traversed by veins filled by the same mineral. A little hæmatite and opacite is scattered about the slide.

102 (Stack of Glen Coul). This rock is not free from difficulty. It consists of quartz and felspar, corresponding with those in the Hebridean gneisses, separated by thin films of a micaceous mineral, more or less dotted with opacite. The structure is undoubtedly fragmental; the rock has undergone great compression, the fragments being crushed, flattened out, and "packed" together, as one sees in slates. I believe it to belong to this newer group; but I could conceive it possible (as my opinion must be formed on a single slide) that we had here a specimen of the older series crushed in an exceptional manner.

103 (below Kinloch Ailsh, pp. 359, 388) consists of minutely fragmental quartz with a little derived mica, imbedded in a matrix chiefly consisting of an earthy material, felsite, and minute scales of the micaceous (or perhaps sometimes hornblendic) mineral already inclusively termed sericite, with a grain or two of magnetite(?). It is in fact not more altered than many of the older Palæozoic slates.

104 (*ibidem*, pp. 359, 388). The "sericite" is rather abundant and conspicuous, giving the rock a little more the appearance of a true schist; but the differences are hardly more than varietal.

107 (Glen Coul, near house, p. 359) is a rock of the same general character, but with the fragments rather larger, looking less compressed, and altogether even less altered. The quartz fragments though small (usually less than .005") are rather markedly angular.

108 (Traligill Burn, Ben More, p. 359). A rock probably of the same group as these last. Shows interbanding on a small scale, bands in which quartz fragments predominate being irregularly interlaminated with finer zones composed chiefly of earthy material and sericite. It is an interesting rock for study, as I think it may be held to represent the first stage in the process of the conversion of an ordinary sedimentary rock into a mica-schist. There are numerous granules and clots of an iron-oxide, and, possibly some minute garnets.

97 (Glen Coul, south side, p. 390), 99 (Ben Arnaboll, p. 403, note). These are peculiar and interesting rocks, closely resembling one another. They may be called quartzites; for the mineral is chiefly quartz; but it is extremely difficult, especially in the former, to detect with certainty the original fragments. Viewed with crossed nicols, the slide appears to be composed of minute granules of quartz of chalcidonic aspect; among these are wavy, somewhat parallel bands, which appear almost homogeneous, but break up like the rest as the

stage is rotated, though occasionally an irregular nucleus appears to remain homogeneous. These give a streaky or somewhat foliated aspect to the slide. There is a little sericite, which enhances this structure. In 97, however, which contains a little hæmatite, some few original elastic grains of quartz may be recognized, together with microcline. I should suppose these rocks to be exceptional varieties of the quartzite group; but the obliteration of the characteristic structure, and the resemblance to the quartzose part of many highly altered mica schists, suggests that the rock may have been originally rather a fine-grained sand or silt, and then, by the action of heat, pressure, and water, almost reduced to a gelatinous silica; so that, as in a schist, many of the minute granules of quartz now visible are of secondary origin.

### *Limestones.*

Of the sedimentary rocks there remain some limestones, more or less crystalline. Although I do not think them of one geologic age, I group them together because it is more difficult to conjecture from its crystalline condition the age of a limestone than that of any other sedimentary rock.

69 (Durness). A rather impure limestone, slightly dolomitic; no distinct trace of organisms, but not more altered than one would expect a Palæozoic limestone to be.

68 (Loch Ailsh). A crystalline limestone, somewhat dolomitized, with a little fragmental quartz and less felspar. Towards the edges of the slide, associated with a little chalcedonic quartz, are some imperfectly developed crystals, above  $\cdot 02''$  long, colourless, of slightly silky aspect, with two cleavages intersecting at about  $80^\circ$ , and an extinction-angle of rather less than  $20^\circ$ , with the edges of the prisms so defined.

67 (Balloch). A generally similar rock, but without the last-named mineral, and with rather more quartz.

105 (South of Ben More Lodge, Loch Ailsh, p. 387). A calc-schist, consisting of calcite or dolomite, quartz, probably both fragmental and secondary, and a micaceous mineral, with some ferrite.

106 (West of Ledbeg, p. 388). A specimen of the remarkable marble discovered by Prof. Heddle. As this rock is now being investigated by himself and others, I shall merely say that it has a finely crystalline matrix of calcite, perhaps somewhat dolomitized, in which are scattered, irregularly and often thickly, subangular to rounded grains of a white pyroxene, probably malacolite, many of which are partially converted into a serpentinous mineral. In one portion of the slide is a structure resembling the "canal system" of *Eozoon*, and, like it, more conspicuous where the calcareous mineral is less distinctly crystallized. For the reason above given, I merely note this fact.

### *Igneous Rocks.*

71 (Traligill Burn, p. 409). This specimen has a ground-mass of rather microcrystalline felspar, plagioclase (so far as we can see in its present condition) predominating in which occurs a considerable

quantity of hornblende. This occurs in fair-sized crystals, with well-defined external form and cleavage, in small elongated prisms and belonites, and in fibrous groups associated with a serpentinous mineral. One or two of the first variety show zonal structure or enclose portions of the matrix. The rock may be called a hornblendic porphyrite.

72 ( $1\frac{1}{4}$  mile east of Altnagalach, p. 409). This is a most perplexing rock. In the slide a fair quantity of black mica is at once recognized, and a number of subtranslucent sap-brown garnets, the larger (being the less regularly formed) including flakes of mica &c. I refer some colourless crystals to apatite. The ground of the slide appears to consist partly of a felspar in patches of a most irregular form (with, perhaps, a little quartz), and a mineral which occurs in rather wavy bunches, like tufts of long thread or of rootlets, or a kind of "canal system." It seems to have replaced the felspar, and may be one of the fibrolite group.

82 (Balloch) consists of a plagioclastic felspar much decomposed, and of a green hornblende intercrystallized with quartz or in clustered microliths. It may be a diorite; but it has been so messed by crushing &c., that it is impossible to be sure. If metamorphic, it belongs to the Hebridean series.

109 (Half-mile N.W. Kinloch Ailsh, p. 409) consists mainly of felspar associated with a little quartz, hornblende, sphene, and iron peroxide. The nature of the felspar is obscured by a kind of micrographitic structure, or root-like intergrowth of quartz. I think I recognize microcline. If igneous, the rock is a kind of syenite; but in its present condition it is difficult to be sure. If not igneous, it belongs to the Hebridean series.

#### DISCUSSION.

The PRESIDENT said that the district about Loch Assynt had always appeared to him to be very difficult; but it was impossible not to admire the pains spent by Dr. Callaway on his paper.

Mr. HUDLESTON said that the author's work evidently was very careful and conscientious. He had himself examined the Assynt country during part of last summer. In the "Assynt series" of the author, the sequence was fairly clear. The Torridon Sandstone and Ben-More grit, each in its own district, formed the base; then came the quartzite, the intermediate group, and finally the dolomite. He thought that there was no "upper quartzite," but that the appearance of it was due to repetition. What had produced that repetition? It was probably the Logan rock. Under that term he included the great gneissoid series with local injections which had figured as the "igneous" rock of former authors. In the mountains of Upper Assynt this formed the core round which the quartzites &c. were folded in great winding sheets. He was not quite prepared at present to accept the absolute identity of the Logan rock with the Hebridean gneiss; there were important petrological differences, recognized by men like Nicol and Heddle. The Logan rock attained an elevation of 2500 feet on the south-east flank of Coniveall; so



that the section exhibited by the author appeared correct in its general principles, the quartzo-dolomites forming a sort of veneer on the front and summit of the mountain. As regards the Dalbeg marbles, these were very singular rocks, mixtures of granular calcite with a pyroxene (?) mineral, whose magnesia was partly in a state of serpentine. He should like to know the relations of the author's Caledonian series with the Hebridean. Dr. Callaway's results corroborated in the main the stratigraphical views of the late Prof. Nicol as to much of the Assynt country. Nicol was understood to have admitted that some of his work in the north-west might not be strictly accurate; but he predicted that the ultimate explanation would take all by surprise.

Mr. TOPLEY asked if Professor Bonney would give his opinion as to the nature of the Logan Rock and of the Dalbeg marble.

Prof. BONNEY said that he had only seen the so-called Logan Rock in one locality in the field, viz. in Glen Logan, near Loch Maree. There in some parts it no doubt had a considerable resemblance to a coarsely crystalline igneous rock; still both macroscopically and microscopically it corresponded better with a granitoid metamorphic rock. In some parts it was certainly a gneiss; almost everywhere it bore marks of great crushing. Some of the dark schists (probably the serpentinous rocks of some authors) proved to be nothing but the Hebridean gneiss crushed near faults. It was certainly not an intrusive rock in Glen Logan. The specimens which he had received from other regions, sent to him by Dr. Hicks, Dr. Callaway, and others, were similar in their nature, Hebridean gneissic rock more or less crushed. If there was igneous rock in the "Logan Rock" it was only local. As regarded the Dalbeg marble, he had not worked much upon it, because he knew that Dr. Heddle had been for some time engaged in studying it. He would merely say that it consisted of crystalline calcite (with, perhaps, dolomite) and a whitish pyroxene (malacolite) partially replaced by a serpentinous mineral. Here and there it showed a structure very like *Eozoon*. He thought from the general appearance of this rock that it would be found to be distinctly of Archæan age.

Prof. LAPWORTH said that he had for some years been of opinion that in the Highlands we must expect to find the same phenomena as in the great mountain-ranges on the continent. He had consequently listened with great pleasure to the paper, the more so as he was personally ignorant of the Assynt district; but Dr. Callaway's interpretation of the structure of that area coincided with what he had himself worked out in the Erriboll district. Here, however, the difficulties were far less than appeared to be the case in the Assynt district. He then pointed to some sections and a map of the Erriboll area, which he had brought with him, showing the Erriboll limestone generally occupying the centre of a synclinal fold, and underlain by a series of flags and quartzites identical with those recognized by Dr. Callaway in Assynt, and repeated again and again in reflexed folds. There was generally a great overfold and fault, which threw the Sutherland series irregularly onto the quart-

zite, the flags, or the limestone; but here and there the quartzite rested in position upon the Arnaboll rock. The latter thus appeared to occupy the stratigraphical place of the upper part of the Hebridean; and as other sections showed it to be followed at once by the typical Hope schists without the intervention of the quartzite, the Erriboll sections appeared to support Dr. Callaway's view, that the whole of the Sutherland series was Archæan.

Dr. HICKS expected to hear some one rise to defend the views maintained by the Geological Survey. The main results announced by Dr. Callaway agreed very well with those at which he himself had arrived in the district further south. The most remarkable thing in the Survey theory was that the more highly you ascended in the succession the more altered the beds became. He was extremely glad to find that the previous speakers, after careful consideration, had arrived, like himself, at views which seemed so much more natural, and that they agreed that the eastern gneiss was not of Silurian but of Archæan age.

Dr. CALLAWAY, in reply to Mr. Hudleston, stated that the Caledonian was certainly distinct from the Hebridean, since in Glen Coul it rested upon the latter with a discordant strike. He had at first been disposed to think that the Arnaboll gneiss was Hebridean, as held by Prof. Lapworth; but he had been led to abandon that view, because between the Arnaboll gneiss and the overlying Hope series there was (1) conformity of dip and strike, (2) an unbroken passage, and (3) a lithological gradation; whereas in Assynt, where the younger gneiss rested upon the Hebridean, there was a complete discordance. He held, however, that if it should be found necessary to revert to his original opinion, the case against the old view would not be weakened, since, on that hypothesis, the Assynt series would be made to dip conformably below both Hebridean and Caledonian, which was absurd; and since there was no break between the two gneisses, it was obvious that the Assynt rocks could not pass between them.

23. FOSSIL CHILOSTOMATOUS BRYOZOA *from* MUDDY CREEK, VICTORIA,  
*&c.* By ARTHUR WM. WATERS, Esq., F.G.S. (Read May 9,  
 1883.)

[PLATE XII.]

THE fossils to be described were collected by Mr. J. Bracebridge Wilson, of Geelong, who obtained them from Muddy Creek, Hamilton; Bird Rock, near Geelong; and Waurm Ponds,—all from the formation which has been called in Australia “Miocene.”

As I had already described Australian Bryozoa from beds of the same age, I undertook the examination of these when Mr. Wilson so kindly sent them to me; and perhaps it would have been better for science if I had not so readily done so, but if a careful observer like Mr. Wilson, who is near the localities, had himself undertaken the description of the collection.

They were sent to me for description with the request that the collection should afterwards be handed over to the Museum of the Geological Society; and I am sure I am only expressing the general feeling of the Fellows when I say that the Society is much indebted to Mr. Wilson for presenting them with collections upon which he had already spent much labour.

Perhaps the most interesting forms are the *Catenicellæ*, a genus which Mr. Wilson was the first to point out occurred fossil (Journ. Micr. Soc. of Victoria, vol. i. p. 60, 1880), giving descriptions of 12 species. Shortly after this I described and figured a few species which I found in the material from Curdies Creek (Quart. Journ. Geol. Soc. vol. xxxvii. p. 309).

In order to understand the fossil *Catenicellæ*, which are represented by 13 species, it became necessary to examine as many calcined and also decalcified species as were available; and while any examination of merely dried specimens cannot supply the place of the study of living animals, or even of spirit-specimens, yet it has brought out several points which are worthy of further investigation. Among others it has shown that as soon as the operculum is removed there is great difficulty in studying the oral aperture, as there is often a notch at the proximal edge, which simulates the sinus of such genera as *Schizoporella*. It also seems that this notch is sometimes replaced by a suboral pore. *C. rufa*, MacGillivray, furnishes a good example of this (fig. 1); for we find, upon separating the operculum, that both the distal and proximal edges are curved upwards, thus giving the operculum a crescentic shape, without any indication of the position of the notch. Thus a portion of the aperture is not closed by the operculum; and here, unless I am mistaken in the appearance, the aperture must be divided into two parts:—

Fig. 1.



first, towards the distal end, the zoœcial oral aperture, which is closed by the operculum; and secondly, below it (proximally) an opening leading to a space between an upper and lower membrane on the front of the zoœcium. To this I refer more fully when dealing with *C. alata* and *C. ampla*, pp. 428, 429.

Since my last contribution was published, a paper has appeared from the pen of Dr. Jules Jullien\*, which should be examined by palæontologists, as it deals with what are now understood as *Membraniporæ*, a group which it has long been felt must be divided up. One division of this was very largely represented in the Chalk; and although we must not be misled into concluding that there were as many species as the almost endless names of d'Orbigny would lead us to suppose, yet a considerable number of species, in different modes of growth, existed then. The most characteristic are those with a thick calcareous expansion, which was covered, when living, with a membrane in which was the opercular opening. The opening of this calcareous expansion Dr. Jullien proposes to call the "opesia," a term which will be useful, as aperture has been used with various significations. In all my recent papers I have always spoken of the orifice closed by the operculum as the oral aperture, a term which I find it most convenient to retain; and aperture I have in this paper used alone in cases in which it is not quite clear what we are dealing with; and, in examining fossils, we shall sometimes find ourselves in this unfortunate position when we have only small fragments to deal with, though probably, when there is sufficient well-preserved material, we shall be able to decipher the structure. This will be the case with such genera as *Micropora* and *Steganoporella*. A very large proportion of the group with the well-marked opesia have also large avicularian cells interspersed among the zoœcia, and Dr. Jullien proposes to call the group Onychocellidæ in consequence.

There is no doubt that the *shape* of the avicularium in such cases is a most useful character; but I do not think that its presence or absence can be made even a specific character, though it was made a generic one by d'Orbigny.

As supporting this, we may point out how important the shape of the zoœcial avicularium has been in specific determination of *Cellaria*; yet we often find large colonies without a single avicularium; and of the common *Cellaria cellulosa* I have had large quantities through my hands in which, after calcining, I failed to detect a single zoœcial avicularium; at other times I have only found a few here and there; on other occasions we may be more fortunate, and find them abundant. So also with *Membranipora angulosa*, Rss., which is living in the Mediterranean: sometimes the zoœcial avicularia are very abundant; other pieces I have found with few, and some with none at all. In the same way I have found chalk-fossils of this group, some with and some without, but yet in mode of growth and in every other respect similar. The genus *Nellia* was described as

\* "Nouvelle Division des Bryozaires Cheilostomiens," Bull. Soc. Zool. 1881.



without avicularia; but since the genus was named by Mr. Busk, I have found a fossil from Australia with them.

We are yet a long way from fully understanding the avicularian organs; but as they are so important in palæontological classification, we may be allowed to examine their function; and *Membranipora angulosa*, a living form, also found fossil, and allied to a large number of cretaceous fossils supposed to be extinct, furnishes the opportunity of doing so. If we remove the avicularian cover (*onychocellaire*) and examine the membrane which it usually protects and covers, we find first of all a small corneous triradiate mark. This serves for the attachment of muscles, which quickly draw the the membrane down when touched; but further, near this there is a small disk with a distinct mark in the centre, and this at once reminds us of the rosette-plates of many of the Chilostomatous and Ctenostomatous Bryozoa. This, I take it, is the tactile organ of Mr. Busk ("Avicularian and Vibr. Organs of the Polyzoa," Quart. Journ. Micr. Science, No. vi. 1854), and to this the endosarc is attached, and this most important structure of the Bryozoon is thus brought into contact with the exterior. It is well known that the avicularia often retain their power of movement when no living polypides fill the cells; but it seems that in this way the colonial life can be maintained.

I have never been able to accept the theory of the prehensile function of the avicularia; and in the case of *Membranipora angulosa* it seems almost as difficult to attribute such a function to them as when we find minute avicularia on the dorsal surface of *Retepora*.

If Dr. Jullien had made one comprehensive genus, *Onychocella*, I should have accepted it; but I believe that the eight genera created by him cannot be distinguished, since, in the first place, the shape of the boundary is variable, and, in the second place, the shape of the opesia can scarcely be considered of generic value. I therefore call all the species *Membranipora*, although feeling that there should be a separation of those with a considerable calcareous expansion\*.

In the same way the genera *Selenaria* and *Lunulites* cannot be looked upon as more than provisional, and will have to be broken up; for *Lunulites incisa* has Schizoporellan characters, while *Selenaria maculata* has the calcareous expansion and opesial opening of such *Membraniporæ* as *M. angulosa*.

A large number of the slides were broken† on the journey; but in the majority of cases, from the boxes in which they were found, there was no doubt as to their origin, though, unfortunately, I am not

\* *Smittipora* I should consider to be *Micropora*, and not closely allied to such a form as *M. angulosa*.

† I have already ("Dry Mounts for the Microscope," Journ. Roy. Micr. Soc. ser. ii. vol. i. pt. i. p. 138, 1881) called attention to the danger of zinc varnish becoming brittle, so that the mount and ring readily spring from the glass or wood when exposed to the shaking of a railway journey. I also pointed out the unadvisability of using metal rings, and would strongly urge naturalists sending slides a long distance to use gold-size and india-rubber rings on glass slips where practicable. I feel convinced that slides mounted in this way would have stood the journey better than those Mr. Wilson sent over.

quite sure as to the locality of a few specimens, and therefore give the two places from which they may have come. These are:—

from Batesford Viaduct or Muddy Creek,

*Cellepora granum.*

— *fossa*, *Hasw.*

— *albicans*, *Hincks.*

*Smittia turrita*, *Sm.*

*Microporella violacea*, var. *fissa.*

and from Muddy Creek or Bird Rock,

*Mucronella mucronata*, *Sm.*

*Microporella violacea*, var. *fissa.*

— *coscinopora*, var. *armata.*

*Schizoporella submersa*, *Waters.*

*Porina coronata*, *Rss.*

*Cellaria angustiloba*, *Busk.*

The collection consists of 62 species, of which 28 are now known living, and 18 of these are found fossil for the first time. But no doubt many of those as yet only known fossil will sometime be discovered living; for we must remember that although so much has lately been added to our knowledge of recent species by such workers as Hincks, MacGillivray, Haswell, &c., there yet remains much to be done, and our knowledge of the Australian recent fauna is very imperfect. This brings the number of Australian fossil Chilostomatous Bryozoa that I have discussed up to 155. To the indication of the age of the deposits I shall have to return when I have my communication on the Cyclostomatous Bryozoa ready.

Three species in the present collection are believed to be identical with fossils from the European Chalk.

### List of Species.

	Page.	Living.	"S.W. Victoria" (Curdies Creek).	Mount Gambier.	Bairnsdale.	Muddy Creek.	Bird Rock.	Waurun Ponds.	Allies and Localities.
1. <i>Catenicella cribriformis</i> , <i>Waters.</i>	428	...	*	...	...	...	*	...	
2. — <i>alata</i> , <i>Thoms.</i>	...	*	*	*	*	*	*	*	
3. — <i>ampla</i> , <i>Waters</i>	429	...	*	*	*	*	*	*	
4. — <i>elegans</i> , var. <i>Buskii</i>	430	...	*	*	*	*	*	*	
5. — <i>solida</i> , <i>Waters</i>	...	...	*	...	*	*	*	*	
6. — <i>internodia</i> , <i>Waters</i>	...	...	*	...	*	*	*	*	
7. — <i>Harveyi</i> , <i>Thoms.</i>	431	*	...	...	...	*	*	*	
8. — <i>ventricosa</i> , <i>Busk</i>	...	*	...	...	...	*	*	*	
9. — <i>hastata</i> , <i>Busk</i>	...	*	...	...	...	*	*	*	
10. — <i>taurina</i> , <i>Busk</i>	...	*	...	...	...	*	*	*	
11. — <i>laevigata</i>	432	...	...	...	...	*	*	*	
12. — <i>longicollis</i>	...	...	...	...	...	*	*	*	<i>C. geminata</i> , <i>Th.</i>
13. — <i>circumcincta</i>	...	?	*	...	...	*	*	*	

## List of Species (continued).

	Page.	Living.	"S.W. Victoria" (Curdies Creek).	Mount Gambier.	Bairnsdale.	Muddy Creek.	Bird Rock.	Wauru Ponds.	Allies and Localities.
14. <i>Cellaria malvinensis</i> , <i>Busk</i> .....	433	*	*	*	*	*			
15. — <i>ovicellosa</i> , <i>Stol</i> .....	"	..	*	*	..	..	*		
16. — <i>angustiloba</i> , <i>Busk</i> .....	"	..	..	*	*	*			
17. — <i>perampla</i> , <i>Waters</i> .....	"	..	..	*	..	..		*	
18. <i>Canda fossilis</i> , <i>Waters</i> .....	"	..	*	*	..	..	*	*	
19. <i>Serupocellaria scabra</i> , <i>Van Ben</i> ..	"	*	..	..	..	..	*	*	
20. <i>Membranipora macrostoma</i> , <i>Rss</i> .....	"	..	*	*	*	*	..	*	
21. — <i>roborata</i> , <i>Hincks</i> .....	"	*	..	..	..	..	..	*	
22. — <i>lusoria</i> , var. <i>coarctata</i> .....	434	..	*	..	..	..	..	*	
23. — <i>articulata</i> , <i>Waters</i> .....	"	..	..	*	..	..	..	*	
24. — <i>oculata</i> , <i>Busk</i> .....	"	*	..	..	..	..	..	*	
25. — <i>arethusa</i> , <i>d'Orb</i> .....	"	..	..	..	..	*	..		
26. <i>Micropora ordinata</i> .....	435	..	..	..	..	..	..	*	
27. — <i>cavata</i> .....	"	..	..	..	..	..	..	*	
28. <i>Monoporella sexangularis</i> , <i>Goldf</i> .....	"	..	..	..	..	*	*	*	
29. — <i>crassatina</i> , <i>Waters</i> .....	"	..	..	*	..	..	..	*	
30. <i>Steganoporella magnilabris</i> , <i>Bsk</i> .....	436	*	*	*	*	..	..	*	Batesford.
31. <i>Membraniporella nitida</i> , <i>Johnst</i> ..	"	*	..	..	..	..	..	*	
32. <i>Cribrilina terminata</i> , <i>Waters</i> .....	"	..	*	..	*	*			
33. — <i>tubulifera</i> , <i>Hincks</i> .....	"	*	..	..	..	*			
34. <i>Mucronella mucronata</i> , <i>Sm</i> .....	"	*	*	*	*	*			
35. <i>Microporella violacea</i> , var. <i>fissa</i> ..	"	*	*	*	*	*			
36. — <i>elevata</i> , <i>Woods</i> .....	"	..	*	*	*	*	..	..	Spring Creek.
37. — <i>yarraensis</i> , <i>Waters</i> .....	"	..	*	*	*	*	..	*	
38. — <i>coscinopora</i> , var. <i>armata</i> .....	"	..	*	..	..	*			
39. — <i>symmetrica</i> , <i>Waters</i> .....	"	..	*	..	..	*	..	*	
40. — <i>Malusii</i> , <i>Aud</i> .....	437	*	..	..	..	..	*		
41. — <i>cellulosa</i> , form <i>adeona</i> .....	"	*	..	..	..	*			
42. <i>Porina coronata</i> , <i>Rss</i> .....	"	*	*	*	*	*	*	..	Orakei Bay &c..
43. <i>Lepralia pertusa</i> , <i>Esper</i> .....	"	*	..	..	..	*			
44. <i>Porella marsupium</i> , <i>MacG</i> .....	"	*	..	..	..	..	..	*	
45. <i>Smittia Tatei</i> , <i>Woods</i> .....	438	..	*	*	*	*	..	*	
46. — <i>reticulata</i> , <i>MacG</i> .....	"	*	..	*	*	*			
47. — <i>Napierii</i> .....	"	..	..	..	..	..	..	*	Napier (New Zealand).
48. — <i>collaris</i> , <i>Norm</i> .....	"	*	..	..	..	..	..	*	
49. — <i>turrita</i> , <i>Smitt</i> .....	"	*	..	..	..	..	..	*	
50. <i>Schizoporella australis</i> , <i>Woods</i> .....	439	..	*	..	..	*	*		
51. — <i>schizostoma</i> , <i>MacG</i> .....	"	*	..	..	..	..	..	*	
52. — <i>submersa</i> , <i>Waters</i> .....	"	..	*	..	..	*			
53. <i>Retepora marsupiatu</i> , <i>Sm</i> .....	"	*	*	*	*	*			
54. — <i>Beaniana</i> , <i>King</i> .....	"	*	..	..	..	*			Crag.
55. <i>Cellepora fossa</i> , <i>Hasw</i> .....	440	*	*	*					<i>Cellepora tubulosa</i> , B.
56. — <i>albicans</i> , <i>Hincks</i> .....	"	*	..	..	*				
57. — <i>granum</i> , <i>Hincks</i> .....	"	*	..	..					
58. <i>Selenaria punctata</i> , <i>Woods</i> .....	"	..	..	..	..	*			
59. — <i>maculata</i> , <i>Busk</i> .....	"	*	..	..	..	*	*		
60. — <i>parvicella</i> , <i>Woods</i> .....	441	..	..	..	..	*	*		
61. — <i>initia</i> .....	442	..	..	..	..	..	..	*	
62. <i>Lunulites petaloides</i> , <i>d'Orb</i> .....	"	..	..	..	..	*	*		

1. *CATENICELLA CRIBRIFORMIS*, Waters.

*Catenicella cribriformis*, Waters, Foss. Chil. Bry. from S.W. Victoria, p. 317, pl. xvi. fig. 39.

*Loc.* Fossil: S.W. Victoria and Bird Rock.

2. *CATENICELLA ALATA*, Thoms. Plate XII. figs. 15, 16.

*Catenicella alata*, W. Thomson, "On new Genera and Species of Polyzoa," Zool. Bot. Assoc. Dublin, 1859, p. 80, pl. vi. fig. 4.

*Catenicella alata*, Waters, Foss. Chil. Bry. from S.W. Victoria, p. 317, pl. xvi. figs. 47, 48, 49; Chil. Bry. from Mt. Gambier, p. 260.

*Catenicella alata*, MacGillivray, Nat. Hist. Vict. decade iii. p. 21, pl. xxiv. fig. 7.

As this seems in many respects to be a very typical *Catenicella*, we may use it for distinguishing the various parts of the *Catenicellæ*. I propose to call the bead containing only one zoecium a globulus;

Fig. 2.

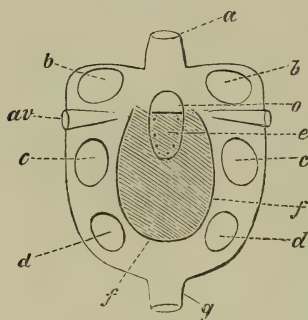


Diagram of globulus of *Catenicella*. *a*, distal tubular connexion; *b*, supra-avicularian compartment; *c*, infra-avicularian compartment; *d*, pedal compartment; *av*, avicularian compartment; *e*, cribriform area; *o*, aperture; *f*, zoecial sac.

those with two zoecia I call a biglobulus. In a globulus there are at the side three compartments, which in the living state are covered with a membrane. The compartment above the avicularium I call the supraavicularian compartment; that below, the infra-avicularian compartment; and the lower one, the pedal compartment. This pedal compartment I consider the equivalent of the vittæ in such species as *C. elegans* &c. In *C. alata* the supraavicularian compartment is very variable, sometimes rising into a prominent spinous process; in others there is no spinous projection. The other two compartments are not so variable, and are usually of moderate size; but until the amount of variation in recent species has been carefully studied, it will be very difficult for palæontologists to determine the *Catenicellæ*. As the shape of fig. 15 varies so much from fig. 16, I have had some hesitation in uniting it with *C. alata*;



but as I have come across many intermediate stages, and find all the characters of *C. alata* present, I think it must be looked upon as identical, though, perhaps, coming from a different part of the colony.

In the recent *C. ventricosa* the spinous process is very variable in the same colony, sometimes being very large and sometimes entirely wanting; and this is also the case in *C. taurina*.

The aperture is 0.07–0.08 mm. wide.

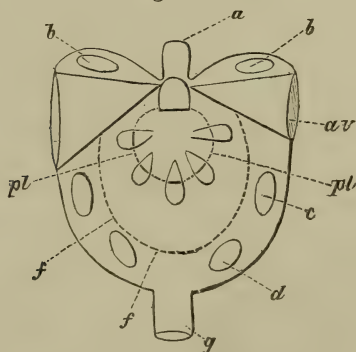
*Loc. Living:* Bass's Straits (*Harv.*), Port Fairy (*Dawson*), Queenscliff (*MacGillivray*), Tasmania (*W.*). *Fossil:* "S.W. Victoria," Mt. Gambier, Muddy Creek, Bird Rock, Waurn Ponds.

### 3. CATENICELLA AMPLA, Waters.

*Catenicella ampla*, Waters, Foss. Chil. Bry. from S.W. Victoria, p. 317, pl. xvi. figs. 46, 50, and Chil. Bry. from Mt. Gambier, p. 259.

This species may be taken as the type of a group of *Catenicella*, which at first sight appears to vary a good deal from the type described when we spoke of *C. alata*, p. 428; but when calcined and decalcified specimens of recent forms are examined, we then find that, although the relative proportions of the different parts vary, yet all the same structures are present. Among recent forms *Catenicella ponderosa*, Goldstein, will perhaps furnish the best example; for upon examining decalcified preparations, the supraavicularian compartment, although very small, can easily be distinguished; on the other hand, the avicularian chamber, instead of being tubular, is very large.

Fig. 3.



Letters as fig. 2. *pl*, protecting plate.

In this group we find a structure which has not yet been described; that is, a calcareous oval plate on the front of the zoecium, and which can be seen through the fenestræ, extending half across them. This structure will be made clear by a reference to the diagram, fig. 3, and to fig. 6, Pl. XII., of the recent *C. ponderosa*, Goldst.,

which is drawn in order to explain it. When such species are decalcified, the oval border of this plate is still distinguishable, and we can also trace a similar oval boundary in other species where there is no calcareous plate. This is the case in *C. margaritacea*: but perhaps this species gives us a clue; for an oval border of about the same size as that of *C. ponderosa* is clearly seen, and here, from the examination of decalcified specimens, there seems to be a chamber of which the boundary is indicated by the oval line, and the notch of the aperture does not represent a sinus, but apparently is an opening into this chamber. I hope that those who have the opportunity of obtaining living specimens will examine this point.

As in so many genera of Bryozoa there is an avicularium or pore below the oral aperture, may we not look upon the typical Bryozoa as having a suboral chamber sometimes closed with an avicularian cover, sometimes without, and with the opening sometimes closed up to the oral aperture? and may not even the adventitious tubules of *Diastopora obelia* and also of some fossil Bryozoa have the same origin?

To the specific description I have to add an avicularium opening laterally, at about the height of the top of the aperture, and an oval protecting calcareous plate on the ventral side of the zoecium below the fenestræ, which are thereby half closed.

#### 4. CATENICELLA ELEGANS, var. BUSKII.

*Catenicella elegans*, Busk, var. *Buskii* (Thoms.), Waters, Bry. from S.W. Victoria, p. 317, pl. xvi. figs. 42, 43.

#### 5. CATENICELLA SOLIDA, Waters.

*Catenicella solida*, Waters, loc. cit. p. 318, pl. xvi. figs. 37, 38.

#### 6. CATENICELLA INTERNODIA, Waters.

*Catenicella internodia*, Waters, Bry. from S.W. Victoria, p. 318, pl. xvi. figs. 78, 79.

In specimens from Muddy Creek, Waurn Ponds, and Bird Rock, the avicularia are rather larger than in the one I figured from S.W. Victoria. There is also a contraction near the lower part of the oral aperture on each side.

#### CATENICELLA INTERNODIA, var. ANGUSTATA.

From Bird Rock there are two very interesting specimens, which in the shape and size of the zoarium are similar to other specimens of *C. internodia*; but on the dorsal surface, instead of the "irregular oval depression," there is a long and broad vitta near the outer border, about the size of that of *C. elegans*, thus showing that the physiological signification of the vitta and broad depression is identical. The front surface is not quite so well preserved, and is more difficult to decipher; but here also the oval depressions have become narrower, and are, in fact, replaced by narrow vittæ, and the central band is replaced by a smooth surface.

It is possible that some may have questioned whether I was

justified in placing *C. internodia* among the *Catenicellæ*; but I think that it will be granted that the present variety shows without any doubt that it was correctly placed.

7. *CATENICELLA HARVEYI*, W. Thomson. Plate XII. fig. 5.

*Catenicella Harveyi*, Wyville Thomson, "On new Genera and Species of Polyzoa," Zool. Bot. Assoc. Dublin, 1859, vol. i. p. 81, pl. vii. figs. 1, 2.

The avicularia in this species are somewhat variable. In most cases they are of moderate size at the side, while in some they are found on raised tubular projections, as figured (5); in others there are two fairly large avicularia directed laterally, and not raised. In one specimen there is on one side an enormous avicularium almost as large as the zoecium. Aperture 0.12 millim. wide. The proximal edge of the aperture is straight.

Thomson, in his description, says that "the cell-walls are very evidently formed of two membranes, which remain distinct."

*Loc.* Living: Bass's Straits (*Th.*). Fossil: Waurin Ponds, Bird Rock, Muddy Creek.

8. *CATENICELLA VENTRICOSA*, Busk.

*Catenicella ventricosa*, Busk, Cat. Mar. Pol. p. 7, pl. ii. figs. 1, 2, pl. iii. figs. 1-5.

*Catenicella ventricosa*, MacGillivray, Nat. Hist. Victoria, decade iii. p. 18, pl. xxiv. fig. 3.

The specimen from Bird Rock has hardly any lateral process, and has the avicularian opening more gaping than in recent species. However, some recent specimens in my possession have not such marked lateral processes as are usually figured. Busk's figure seems to show that the upper pore sometimes forms a notch; but none of my specimens show more than a faint trace of one.

*Loc.* Living: Bass's Straits, 45 fathoms (*B.*), Victoria (*MacG.*), Tasmania (*A. W. W. coll.*), Van Diemen's Land (*Harv.*), Port Fairy (*Dawson*). Fossil: Bird Rock.

9. *CATENICELLA HASTATA*, Busk.

*Catenicella hastata*, Busk, Cat. Mar. Pol. p. 7, pl. ii. figs. 3, 4; MacGillivray, Nat. Hist. of Victoria, decade iii. p. 19, pl. xxiv. fig. 4.

I have specimens of *C. hastata* from Victoria sent to me marked *C. compressa*, and also a specimen so named without further indication than Australia, which, upon examination, turns out to be *hastata*. The fossil does not seem to differ from the recent form in size or in any other respect.

*Loc.* Living: Bass's Straits, 45 fathoms, New Zealand (*B.*), Victoria, frequent (*MacG.*). Fossil: Bird Rock and Waurin Ponds.

10. *CATENICELLA TAURINA*, Busk.

*Catenicella taurina*, Busk, Cat. Mar. Poly. p. 12, pl. xi.

There is one biglobulus from Bird Rock which is not very well

preserved. The surface is smooth, and on each side, a little lower than the aperture, there is a small oval opening. The oral aperture is rounded above, and on each side near the base there is a minute denticle.

In a recent specimen from Natal the lower cells are attached to the ground by a bundle of tubular fibres, of which several are attached to each globulus. The bundle is naturally thickest in the lowest part. The lower cells have all well-marked avicularia, usually one on each side, but no "spines" (of Busk); while in the upper cells the avicularia are rarer, and a spine on each side is well developed. In the upper cells, with two well-developed spines, I do not find any avicularia. As I have elsewhere remarked, it is very important that the globuli from various parts of a colony should be compared.

*Loc.* Living: Algoa Bay (Busk), Natal (A. W.). Fossil: Bird Rock.

11. *CATENICELLA LÆVIGATA*, sp. nov. Plate XII. fig. 1.

This has very few characters on which to make a species, and in its simplicity differs from most of the *Catenicella*. The shape of the globulus is cuneiform, surface coarsely punctate. The zoecia are almost tubular, and are nearly parallel on each side of the axis. The aperture is circular at the distal end with a rounded notch on the proximal; but whether this is an oral sinus or only simulates one in the way mentioned on page 423, I am as yet unable to say. Dorsal and anterior surface smooth. Oral aperture 0.04 millim. wide. This will probably be the smallest aperture of any Chilo-stomatous Bryozoon yet described.

From Bird Rock.

12. *CATENICELLA LONGICOLLIS*, sp. nov. Plate XII. figs. 2, 3, 4.

Globulus cuneate, surface smooth, with a large avicularium at each upper corner; opening of avicularium turned rather more towards the dorsal surface than the ventral; mandibular opening narrow, curved, with the mandible directed upwards. An oval vitta marked with transverse lines, just below the aperture, also a very minute vitta on each side near the base. Aperture nearly circular, with a broad wide notch below. Dorsal surface smooth, rounded, raised to the centre of the zoecium. The tubular connexion from one globulus to another very long, in some cases about half as long as a zoarium. Closely allied to *C. geminata*, Thoms. Oral aperture 0.06 millim. wide.

*Loc.* Fossil: Bird Rock, Muddy Creek, and Waurin Ponds.

13. *CATENICELLA CIRCUMCINCTA*, sp. nov.

Globulus ovate, with a row of large foramina round the margin of the zoecium, and one pore below the aperture. Aperture large, rounded above, widest at the proximal edge, which is straight. Oral aperture 0.08 millim. wide and 0.08 millim. long.



This only differs from *Catenicella pulchella*, Maplestone\* (afterwards described by MacGillivray † as *Catenicella concinna*), in having a large pore below the aperture instead of a notch in the aperture. But we often find the suboral pore close up to the aperture; and I believe that we shall find that the notch is represented by this suboral pore; I therefore had much hesitation in giving a new name, which I anticipate will not be permanent.

*Loc.* Fossil: Muddy Creek, Bird Rock, and Waurn Ponds.

14. *CELLARIA MALVINENSIS*, Busk.

15. *CELLARIA OVICELLOSA*, Stol.

16. *CELLARIA ANGUSTILOBA*, Busk.

*Melicerita angustiloba*, Busk, Quart. Journ. Geol. Soc. vol. xvi. p. 261.

*Cellaria angustiloba*, Waters, Foss. Chil. Bry. from Mt. Gambier, Q. J. G. S. vol. xxxviii. p. 260, pl. ix. figs. 28, 29, 30.

*Loc.* Fossil: Mount Gambier (*Woods & Wat.*), Orakei Bay (*Stol.*), Bairnsdale (*W.*), Muddy Creek, and second specimen from Muddy Creek or Bird Rock.

17. *CELLARIA PERAMPLA*, Waters.

*Cellaria perampla*, Waters, Foss. Chil. Bry. from Mt. Gambier, p. 260.

*Loc.* Mount Gambier, Waurn Ponds.

18. *CANDA FOSSILIS*, Waters.

19. *SCRUPOCELLARIA SCABRA*, Van Beneden.

20. *MEMBRANIPORA MACROSTOMA*, Rss.

For synonyms see "S.W. Victoria," p. 323.

This is closely allied to *Membranipora roborata*, Hincks; but the zoecia of *M. macrostoma* are twice the size of those of *M. roborata*.

21. *MEMBRANIPORA ROBORATA*, Hincks.

*Membranipora roborata*, Hincks, Gen. Hist. of Mar. Poly., Ann. & Mag. Nat. Hist. ser. 5, vol. viii. p. 69, pl. ii. fig. 3.

The fossil fragment from Waurn Ponds is very small and occurs with only one layer, or, as we may say, in the *Hemeschara* form; and a recent specimen in my possession from New Zealand, which was sent me by Miss E. C. Jelly as *M. roborata*, has also only one layer, and, like the fossil, only one avicularium above the zoecium, not two, as described by Mr. Hincks. In the recent *M. roborata* a radicle tube from the base of each external zoecium unites with those of the neighbouring zoecia to form "the thickened rib along the margin," as described by Mr. Hincks. In the fossil there are four zoecia in a longitudinal row. *Opesia* 0.18 millim. long.

*Loc.* Living in bilaminate condition off Curtis Island (*H.*); in unilaminate condition, New Zealand. Fossil: Waurn Ponds.

\* "New Species of Polyzoa," Journ. Micr. Soc. of Victoria, vol. i. nos. 2, 3, p. 64, pl. v. fig. 4.

† "On some new Species of *Catenicella*," Roy. Soc. Vict. 1880.

## 22. MEMBRANIPORA LUSORIA, var. COARCTATA. Plate XII. fig. 20.

*Membranipora lusoria*, Waters, Foss. Chil. Bry. from S.W. Victoria, p. 324, pl. xiv. fig. 14, pl. xviii. fig. 82.

The specimen from Wauru Ponds has two large bosses nearly meeting across the opesia (aperture).

The figure is by an accident drawn slightly too large.

This is allied to *Cellaria cactiformis*, d'Orb. (Pal. Fr. pl. 651. figs. 1-4).

*Loc.* Fossil: Wauru Ponds.

## 23. MEMBRANIPORA ARTICULATA, Waters.

*Membranipora articulata*, Waters, Foss. Chil. Bry. from Mt. Gambier, p. 264, pl. viii. figs. 15, 16.

## 24. MEMBRANIPORA OCULATA, Busk. Plate XII. fig. 22.

*Nellia oculata*, Busk, Cat. Mar. Pol. p. 18, pl. lxiv. fig. 6, pl. lxv. fig. 4.

*Nellia oculata*, Smitt, Floridan Bryozoa, p. 3, pl. i. figs. 53, 54.

*Nellia oculata*, MacGillivray, Nat. Hist. Vict. decade v. p. 51, pl. 49. fig. 5.

In the fossil the avicularia are larger and more raised than in any recent specimen which I have seen, and there are four spines above the aperture of each zoecium, on which account it should perhaps be called var. *spinosa*. Length of opesia 0.15 millim.

*Loc.* Living: Torres Straits, 9 fathoms (*B.*); Bass's Straits (*Thoms.*); Florida, 13-138 fathoms (*Sm.*); Queenscliff, parasitic on algæ and zoophytes (*MacG.*); Holborn Island, Queensland (*Haswell*); Cape Grenville, N.E. Australia, 20 fathoms (*A. W. W. coll.*); Piper Islands, 9 fathoms (*A. W. W. coll.*). Fossil: Wauru Ponds.

## 25. MEMBRANIPORA ARETHUSA, d'Orb. Plate XII. fig. 19.

*Eschara arethusa*, d'Orb. Pal. Franç. p. 127, pl. 666. figs. 4-6.

*Eschara actæa*, d'Orb. loc. cit. p. 116, pl. 662. fig. 17.

*Eschara allica*, d'Orb. loc. cit. p. 125, pl. 665. figs. 8, 10.

The specimen from Muddy Creek has 12 longitudinal rows of zoecia in a compressed branch in the *Eschara*-form. The zoecia are of the same size as those in a specimen I collected from the Cretaceous beds of Royan (France), and the aperture (opesia) is also of the same size and in a similar position; the sides of the zoecia, however, are somewhat straighter and not so much contracted below as in the Chalk specimen. In the Royan specimen there is a zoecial avicularium (*onychocellaire*), while I do not find one in the Australian fossil.

This is also allied to *Semieschara disparilis*, d'Orb., and many other species described by d'Orbigny.

Width of the opesia 0.16 millim., length of opesia 0.25 millim.

*Loc.* Cretaceous of France. Muddy Creek.

26. *MICROPORA ORDINATA*, sp. nov.

Zoarium in *Eschara*-form (flat piece about  $\frac{1}{2}$  inch square). Zoecia flat, separated by a wide margin, depressed, especially at the distal end, oblong, arched above, with few large granulations and few pores. Oral aperture close up to the distal end, rounded above, straight below, with a raised lip. It would seem to be a *Micropora* and not a *Steganoporella*, but the two genera are difficult to distinguish in the fossil state. This seems to be somewhat similar to *Eschara verrucosa*, T. Woods (non Peach), "On some Tert. Austral. Polyzoa," Tr. Roy. Soc. N. S. W. 1876, p. 2, fig. viii.; but it differs in not having the aperture about the middle of the zoecium as figured, and also in the absence of marginal pores. Aperture 0.3 millim. wide.

Loc. Waurn Ponds.

27. *MICROPORA CAVATA*, sp. nov.

Zoarium in *Eschara*-form foliaceous. Zoecia hexagonal, the area round the aperture very much depressed. The aperture is about a third of the length of a zoecium from the distal end, semi-circular, with a very distinct lip directed vertically upwards, strengthened at each end by a thickening. Above the aperture the cell-wall is often much thickened, forming a hood to the aperture. Width of aperture 0.25 millim.

Loc. Waurn Ponds.

28. *MONOPORELLA SEXANGULARIS*, Goldf.

*Eschara sexangularis*, Hagenow, Maestrichter Kreide, p. 81, pl. x. figs. 3, 4, 5.

*Eschara Clarkei*, T. Woods, "On some Tertiary Australian Polyzoa," Tr. Roy. Soc. N. S. Wales, 1876, p. 2, figs. iv.-vii.

This seems to be the same species as one I have from Maestricht which I have called *sexangularis*, though with a little doubt, as I cannot find any zoecial avicularia. The zoecia from Bird Rock are slightly larger than those from Maestricht; but the aperture is of the same size. I do not understand what Mr. Woods means by "pore for the avicularium upon the summit," as there is nothing of the kind in my specimens and he does not show it in his figures. This would seem to be allied to *Semieschara disparilis*, d'Orb. (Pal. Fr. pl. 709. figs. 9-12).

In a specimen from Bird Rock a small indentation on each side of the base of the aperture shows us that we are dealing with the oral aperture and not with an opesia opening; and it is therefore placed with *Monoporella*. Aperture 0.37 millim. wide.

Loc. Muddy Creek (*Woods*, and *Wilson's coll.*). Bird Rock and Waurn Ponds.

29. *MONOPORELLA CRASSATINA*, Waters.

*Monoporella crassatina*, Waters, On Foss. Chil. Bry. from Mt. Gambier, Quart. Journ. Geol. Soc. vol. xxxviii. p. 270, pl. vii. fig. 8.

Loc. Mt. Gambier (*W.*), Napier, New Zealand (in Miss Jelly's collection as recent Tertiary). Waurn Ponds.

## 30. STEGANOPORELLA MAGNILABRIS, Busk.

## 31. MEMBRANIPORELLA NITIDA, Johnst.

*Membraniporella nitida*, Hincks, Brit. Mar. Pol. p. 200, pl. xxvii. figs. 1-8.

*Lepralia eximia*, Seguenza, Le Form. Terz., R. Accad. dei Lincei, anno cclxxvii. 1880, p. 203, pl. xiv. fig. 23.

In the fossil from Waurin Ponds the zoecia are inclined to be hexagonal. The mesial line of the zoecium is carinate, with about 9 ribs on each side. Width of the oral aperture 0.14 millim.

This is closely allied to *Pliophlæa sagena*, Gabb & Horn, from the Cretaceous of New Jersey.

*Loc.* Living: Britain, Northern Seas, Roscoff, New Zealand (*Hutton*); Capri from 225 fathoms (*A. W. W. coll.*). Fossil: Zanclean of Calabria (*Seg.*), Waurin Ponds.

## 32. CRIBRILINA TERMINATA, Waters. Plate XII. fig. 17.

*Cribrilina terminata*, Waters, Bry. from S.W. Victoria, p. 326, pl. xvii. fig. 68, and Chil. Bry. from Bairnsdale, p. 507, pl. xxii. fig. 6.

In one specimen from Muddy Creek there are several large zoecial avicularia directed downwards. By the side of one zoecium there are also narrow, almost acicular avicularia directed laterally.

*Loc.* Fossil: S.W. Victoria, Bairnsdale and Muddy Creek.

## 33. CRIBRILINA TUBULIFERA, Hincks.

*Cribilina tubulifera*, Hincks, "Gen. Hist. Mar. Polyz.," Ann. & Mag. Nat. Hist. ser. 5, vol. viii. p. 56, pl. i. fig. 7 (1881).

The fossil has an aperture 0.12 millim. wide, grows incrusting shells, and seems to be distinct from my *C. suggerens*.

*Loc.* Living: Bass's Straits (*H.*). Fossil: Muddy Creek.

## 34. MUCRONELLA MUCRONATA, Sm.

## 35. MICROPORELLA VIOLACEA, Johnst., var. FISSA, Hincks.

*Microporella violacea*, var. *fissa*, Waters, Bry. from S.W. Vict. p. 329, pl. xv. fig. 26, pl. xvii. fig. 73.

## 36. MICROPORELLA ELEVATA, T. Woods.

## 37. MICROPORELLA YARRAENSIS, Waters.

## 38. MICROPORELLA COSCINOPORA, Rss., var. ARMATA, Waters, loc. cit. p. 331, pl. xv. fig. 25.

## 39. MICROPORELLA SYMMETRICA, Waters.

*Microporella symmetrica*, Waters, Foss. Chil. Bry. from S.W. Victoria, p. 332, pl. xviii. fig. 83.

From Muddy Creek there are several pieces of straight compressed branches about 1.5 millim. broad. In one case there is a large avicularium directed upwards at the side of the zoarium.



## 40. MICROPORELLA MALUSII, Aud.

Only two zoëcia from Bird Rock.

Loc. Living : European Seas, S. America, New Zealand, Australia.  
Fossil : English Crag and Pliocene of Italy.

## 41. MICROPORELLA CELLULOSA, MacG., form ADEONA.

*Dictyopora cellulosa*, MacGillivray, Trans. Roy. Soc. Vict. 1868.

*Adeona cellulosa*, Kirchenpauer, "Ueber die Bryozoen-Gattung *Adeona*," Journ. Mus. Godeffroy, 1879, p. 10.

*Dictyopora cellulosa*, MacGillivray, Nat. Hist. Vict. decade v. p. 37, pl. 47. fig. 1, & decade vii. pl. lxvi. fig. 1 e.

From the examination of some recent specimens, I am convinced that we should place this with *Microporella*. Although I was unable to prepare out any opercula, yet sections showed me that the proximal edge of the oral aperture was straight, and there are two contractions near the base of this aperture. The oral aperture is at a slight distance from the surface, and what has been described as a round aperture is really a peristome.

In recent specimens of *M. cellulosa* and *albida* the suboral pore is round; but in the fossil, though most pores seem to be round, yet there are a few slightly elongated and denticulated. The interior of the shell is hollowed out round the region of the oral pore.

*M. cellulosa* is closely related to *M. violacea*, var. *fissa*, a species which shows great variation both in the size of the avicularium and of the elevation of the front of the cell. In small pieces, such as the fossils in question, it is very difficult to distinguish between *M. cellulosa*, *M. grisea*, and *M. albida*.

In *M. albida*, form *Adeona*, there are large zoëcial avicularia near the borders of the fenestræ, which have the same form as the smaller avicularia on the front of the zoëcium; and we may ask if this is not a case of the avicularium having enormously developed at the expense of the polypide. Perhaps this may be the way in which many zoëcial avicularia have originated. Those who dredge these species should examine to see whether the frequency of these large avicularia depends upon any special condition, such as depth or the nature of the sea-bed.

Loc. Living : Queenscliff. Fossil : Muddy Creek.

## 42. PORINA CORONATA, Rss.

This occurs from Muddy Creek in what I call the *b* form (Bry. S.W. Vict. p. 334) and from Bird Rock in the *c* form.

## 43. LEPRALIA PERTUSA, Esper.

## 44. PORELLA MARSUPIUM, MacG.

*Lepralia marsupium*, MacG. Trans. Roy. Soc. Vict. 1868, and Nat. Hist. of Victoria, decade iv. p. 22, pl. 35. fig. 4.

*Porella marsupium*, Hincks, Contr. towards Gen. Hist. of Mar. Pol., Ann. & Mag. Nat. Hist. Aug. 1881, pl. i. fig. 6.

*Porella marsupium*, MacGillivray, "Descriptions of new or little-known Polyzoa, pt. iii.," Tr. Roy. Soc. Vict., 1882, extra page.

Mr. Ridley, in his description of a zoological collection from the Straits of Magellan, describes a species as *Schizoporella marsupium*, MacG.; but this Mr. MacGillivray has since called *S. Ridleyi*.

Width of oral aperture of the fossil 0.07 millim.

*Loc.* Living: Victoria (MacG.); Bass's Straits (H.). Fossil Wauru Ponds.

45. *SMITTIA TATEI*, T. Woods.

46. *SMITTIA RETICULATA*, MacG.

47. *SMITTIA NAPIERII*, nov. Plate XII. fig. 14.

Zoarium incrusting. Zoecia small, ovate, with very slight peristome, large punctures round the edge; oral aperture nearly flat on the lower edge; an opening (probably avicularian) just below the aperture almost into the peristome. Large acute avicularia, directed outwards, placed nearly halfway down the zoecia. Ovicell raised, globose.

I have a specimen, fossil, sent me by Miss Jelly, from "recent Tertiary," Napier, New Zealand, and as it is better preserved than the one from Wauru Ponds, I have figured it.

*Loc.* Fossil: Napier, New Zealand; Wauru Ponds.

48. *SMITTIA COLLARIS*, Norm., var. Plate XII. fig. 10.

I have always found the greatest difficulty in distinguishing between *Phylactella* and *Smittia*, and have already expressed my doubts as to the advisability of using the shape of the peristome as a generic character; and the present form, which is closely allied to, if not identical with, *Phylactella collaris*, Norm., has decided me to only use the name *Smittia* for what are looked upon as belonging to these two genera.

The peristome is variable, and is thicker and higher at both sides, thus forming a depression in its proximal part; the distal part of the peristome is also separated, and rises in a tongue-shaped form.

The peristome of a recent species, which I collected in Rapallo, N. Italy, and which I consider the same as *Lepralia obeliscus*, Manz., and also perhaps as *L. Gotriana*, Rss., has a similar tongue-shaped distal portion. The surface of the fossil is granular. Aperture 0.17 millim. wide.

Occasionally the peristome is entire, when there is little difference from that of the British *P. collaris*; the peristome rising on each side reminds us of *Phylactella eximia*, Hincks; but in *P. collaris* the sides are sometimes raised above the rest of the peristome.

*Loc.* Fossil: Wauru Ponds and Wauru Quarry.

49. *SMITTIA TURRITA*, Sm.

*Lepralia turrita*, Smitt, Floridan Bryozoa, p. 65, pl. xi. figs. 226-228.

The specimen, which was collected either from Batesford or from Muddy Creek, is in the *Cellepora* form, the zoarium consisting of

many layers, and the zoœcia are heaped together and irregularly disposed. There are usually only two "stout marginal spines," not four as described by Smitt in the specimen from Florida, and in the Australian fossil these are very irregularly placed. The oral aperture is nearly round, and of the same size as in the Floridan specimen, viz. 0.15 millim. wide.

In the aperture there are three denticles, similar to those in *Smittia reticulata*, and therefore I unite it with that genus, though not without much doubt as to where it should be placed.

*Loc.* Living: Florida, 26-44 fath.

50. SCHIZOPORELLA AUSTRALIS, T. Woods.

*Tetraplaria australis*, T. Woods, Tr. Roy. Soc. N. S. Wales, 1878, p. 5. fig. 4.

*Schizoporella australis*, Waters, Bry. from S.W. Victoria, p. 341, pl. xiv. fig. 15.

A specimen from Bird Rock has fine granulations and fine pores, as described in my former paper, p. 341.

*Loc.* Muddy Creek (*Woods*); S.W. Victoria (*A. W.*); Bird Rock.

51. SCHIZOPORELLA SCHIZOSTOMA, MacG.

*Lepralia schizostoma*, MacGillivray, Nat. Hist. Vict. deca deiv. p. 33, pl. 38. fig. 6.

The zoœcia are small, ovate, with a small oral aperture and large globose ovicell. Immediately below the oral aperture there is an avicularian prominence, which is not described by MacGillivray, but is figured about the centre of the front of the zoœcium. Width of oral aperture 0.05 millim.

*Loc.* Living: Williamstown and Queenscliff. Fossil: Waurin Pond Quarry, Suffolk Crag (*A. W. W. coll.*).

52. SCHIZOPORELLA SUBMERSA, Waters.

*Schizoporella submersa*, Waters, Bry. S.W. Vict. p. 340, pl. xviii. fig. 5.

Fossil: Curdies Creek (*W.*), Muddy Creek.

53. RETEPORA MARSUPIATA, var. MUCRONATA. Plate XII. fig. 13, 21.

This differs from most specimens of *R. marsupiat*a in having a very large oval avicularium below the aperture; but we see in Smitt's fig. 248 (Floridan Bry.) that there is sometimes such an avicularium; above this the peristome rises into a mucro. The opening on the front of the ovicell is wide, pointed above and rounded below. The dorsal surface is divided into nearly equal areas by an irregular line running down the middle, from which lines branch off; at the base of each dorsal division there is a narrow avicularium directed diagonally downwards (see fig. 36, pl. xv. Bry. fr. S.W. Vict.).

*Loc.* Fossil: Muddy Creek.

54. RETEPORA BEANIANA, King.

*Retepora Beaniana*, King, Ann. Nat. Hist. vol. xviii. 1846, p. 237;

Hincks, Brit. Mar. Polyzoa, p. 391, pl. liii. figs. 1-5. (See Hincks for synonyms.)

In the fossil from Muddy Creek the central zoecia have a rounded avicularium, directed downwards, within the aperture; but the outer zoecia have a subspatulate avicularium directed laterally.

It is somewhat doubtful if the species described by Stoliczka is really *R. Beaniana*.

*Loc.* Fossil: Muddy Creek and English Crag.

55. *CELLEPORA FOSSA*, Haswell.

56. *CELLEPORA ALBICANS*, Hincks.

57. *CELLEPORA GRANUM*, var. Plate XII. fig. 18.

*Cellepora granum*, Hincks, Gen. Hist. of Mar. Polyzoa, p. 68, pl. iii. fig. 8; Ann. & Mag. Nat. Hist. Aug. 1881.

The fossil varies in having the peristome closed in, which thus forms an elongate tube. In *Cellepora Costazii*, Aud., from the Mediterranean, a similar variation is found; for occasionally the peristome is entirely closed.

*Loc.* Fossil: Batesford or Muddy Creek.

58. *SELENARIA PUNCTATA*, T. Woods.

*Selenaria punctata*, T. Woods, "On some Recent and Fossil Species of *Selenariadæ*," Trans. Phil. Soc. Adelaide, 1879, p. 9, pl. ii. fig. 8.

The large pores below the aperture are denticulated, as are also the rosette plates. The vibracular areas are broken; but they are so similar in character to those of *Selenaria maculata* that I should expect that in perfect specimens they will be found covered with a cribriform calcareous expansion. Aperture 0.21 millim. wide.

This species is very closely allied to *Caleschara denticulata*, MacG. (Nat. Hist. Victoria, decade v. p. 45, pl. xlviii. fig. 8).

*Loc.* Living: Cape Three Points, Australia (*Woods*), 71 fath. Fossil: Muddy Creek.

59. *SELENARIA MACULATA*, Busk. Plate XII. figs. 7, 9, 12.

*Selenaria maculata*, Busk, Cat. Mar. Pol. p. 101, pl. cxvii.

The shape of the opesia in the fossil is slightly different from that of recent specimens in my possession from Holborn Island; and I therefore give figures of both for comparison. In the fossil the zoecia and aperture are somewhat wider than in the recent specimens, and the lip is nearly as broad as the opesia, whereas in the recent specimens this lip is narrow and almost spicular. Some authorities may think that on this account the fossil ought to be called a variety; others perhaps would attach specific value to this difference.

The way in which the *Selenariadæ* begin to grow is a subject worthy of complete investigation; but in the meantime the few specimens in my possession throw some light upon it. The fossil has grown upon a small stone, probably crystalline; and upon



breaking up recent specimens I found, placed as a nucleus, either a grain of sand or a minute Foraminifer, as shown semidiagrammatically in fig. 12. The first cells are much smaller than the later ones and very shallow; and the calcareous growth of the *Selenaria* will completely surround the grain of sand &c.

I have *Cupularia stellata*, B., living, from near Capri, which there grows upon small shells and stones, and sometimes only covers the shell; in other cases, where the stone or shell is small, it spreads over and grows free, thus assuming the form of the *Selenariadæ*. We thus see that at the commencement the mode of growth of the group is truly Membraniporidan.

In *Cupularia umbellata* from the Antwerp Crag, and also from the Pliocene of N. Italy, I have found a nuclear grain of sand upon which the colony has grown.

Stoliczka, when speaking of *Lunulites latdorfensis*, says (Olig. Bry. von Latdorf, p. 94) that the point of attachment is at the top, and points out that this is curious, as it is usually below; but surely the fact must be that the upper part has been broken away, and the shell upon which the young colony has grown is thus exposed.

In my paper on Bryozoa from S.W. Victoria, page 345, I suggested that it was perhaps by an error of the lithographer that Mr. Woods's figures of the *Selenariadæ* were drawn upside down; but as they have been figured and described thus by a large number of our leading authorities, it is as well to point out that the distal end of the zoecium must of course always be that which is nearest the growing end of the colony; and this we are always able to decide by means of the operculum, as the hinged end will be the proximal, while the free end is the distal or upper end.

I would ask a question which only those who dredge in Australia can answer. It is whether, since such a form as *Selenaria maculata* grows upon a grain of sand, we do not thus, by its presence, obtain an indication as to the sea-bottom of the locality where it grows?

*Selenaria alata*, T. Woods, seems very closely allied to this. Width of opesia, at the widest part, 0.19 millim.; in the middle 0.13 millim. The width of the opercular aperture in a recent specimen is 0.12 millim.

Loc. Living: Bass's Strait (B.); Holborn Island (Haswell). Fossil: Muddy Creek, Bird Rock.

#### 60. *SELENARIA PARVICELLA*, T. Woods.

*Selenaria parvicella*, T. Woods, "On some Recent and Fossil Species of Australian *Selenariadæ*," Trans. Phil. Soc. Adelaide, 1880, p. 10, pl. ii. fig. 10.

The specimen from Bird Rock is but badly preserved. A calcareous expansion, sloping inwards, about half covers the front of the zoecium. The opesia is thus nearly semicircular. Average width of opesia 0.19 millim.

Loc. Fossil: Muddy Creek (Woods), Bird Rock.

61. *LUNULITES INITIA*, sp. nov. Plate XII. fig. 8.

Zoarium subconical, small, 1 millim. in diameter. Zoecia oval, surface granulated, concave, separated by a raised border. Aperture rounded above, with a real or apparent sinus below. A few conical cells, with three large pores between the zoecia and at the edge of the zoarium. Base of zoarium showing each zoecium raised and radiating from the centre.

*Loc.* Waurn Ponds.

62. *LUNULITES PETALOIDES*, d'Orb. Plate XII. fig. 11, *a, b, c.*

*Lunulites petaloides*, d'Orb. Pal. Franç. p. 353, pl. 705. figs. 6, 9.

*Lunulites androsaces* (of Allioni), Manzoni, Bri. Plioc. Ital. cont. 1 *a*, p. 12, pl. ii. fig. 18, and Bri. Foss. del. Mioc. d'Aust. ed Ungh. p. 25 (73), pl. xvii. fig. 57.

*Lunulites distans*, Gabb & Horn, Monogr. Foss. Pol. of Second. and Tert. Form. of N. Amer., Ac. Nat. Sc. Philad. vol. v. pt. ii. p. 119, pl. xix. fig. 4.

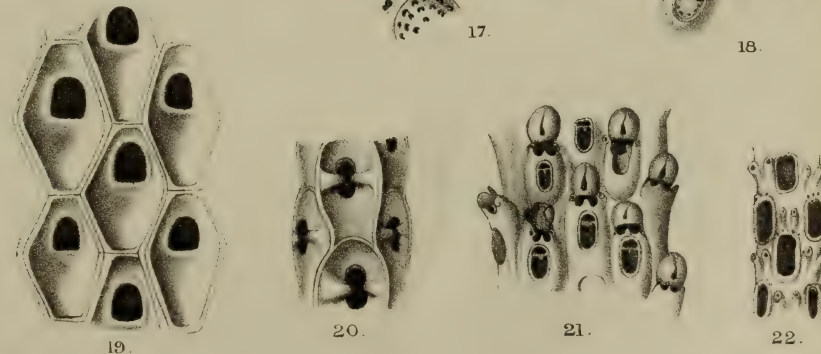
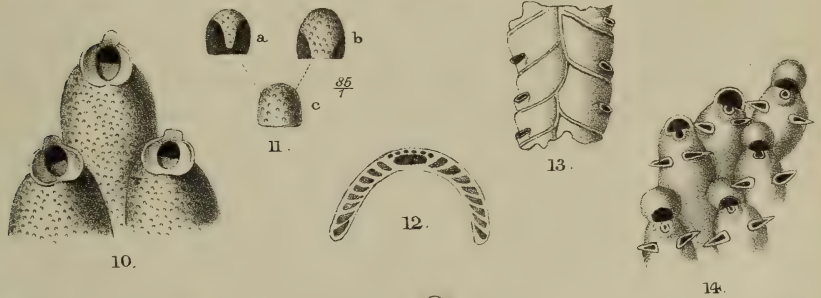
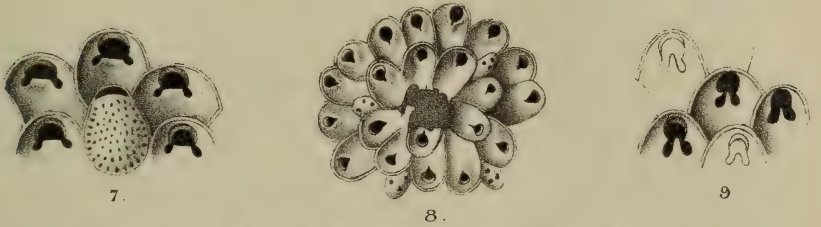
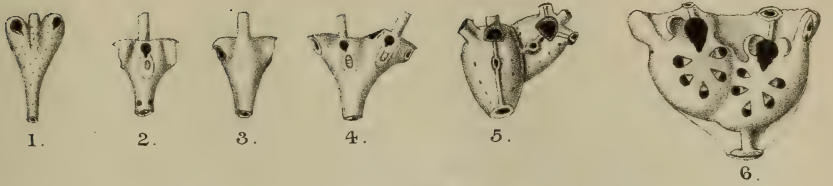
*Oligotresium vicksburgensis*, Gabb & Horn, loc. cit. p. 139, pl. xix. fig. 22.

*Lunulites cupola*, T. Woods, "On some Recent and Fossil Species of Selenariadæ," Trans. Phil. Soc. Adelaide, 1880, p. 8, pl. i. fig. 5*a, c.*

Zoarium conical. Zoecia oval to hexagonal, area depressed, slightly raised round the aperture, surface granular. Aperture (oral or opesia) straight below, rounded above. Vibracula usually forming a row between the radial zoecia, but sometimes fewer, and irregularly spread over the zoarium; opening of vibracula elongate, with a process projecting from each side, which are sometimes equal, but in other cases the projection on the left is much larger and toothed. Central zoecia smaller, frequently closed with a granular calcareous mass. This commences inside the *distal* end of the aperture, and is subtriangular, hanging down inside the aperture like the human tonsil in the throat. It becomes gradually wider until the whole aperture is closed.

In one specimen the vibracula are placed quite regularly in radial rows; in two others, in which both zoecia and vibracula are rather larger, there are fewer vibracula, and these are not regularly placed.

This is a species which lived through the Cretaceous, Miocene, and Pliocene; and it and its allies were widely distributed in Cretaceous and Miocene times. The list of synonyms ought to be very large; but as the description, in some cases, leaves it doubtful, I only mention, as belonging to the group, if not to this species:—*Lunulites Goldfussi*, Hag.; *L. Hagenowi*, Bosq.; *L. quadrata*, Rss.; *L. hæmisphæricus*, Röm.; *L. microporus*, Röm.; *Discoescharites mammillatus*, Röm.; *L. latdorfensis*, Stol.; *L. conicus*, Busk; *L. apertus*, T. Woods; *L. exiguus*, T. Woods; *L. Bourgeoisii*, d'Orb.; *L. regularis*, d'Orb., *L. cretaceus*, Defr. If a new species is to be made each time that the shape of the zoarium varies, we can then make an enormous number of species of *Lunulites*: and for those who are fond of







making genera, I would call attention to a method which Messrs. Gabb and Horn have unconsciously hit upon, as upon one plate the same species is figured right way up and upside down, thus giving two good genera.

I am not sure that this ought to be separated from *S. marginata*, Woods.

## EXPLANATION OF PLATE XII.

- Fig. 1. *Catenicella lævigata*, sp. nov.,  $\times 25$ .  
 2, 3, 4. — *longicollis*, sp. nov.,  $\times 25$ .  
 5. — *Harveyi*, Thoms.,  $\times 25$ .  
 6. — *ponderosa*, Goldst., recent, showing the protecting plate,  $\times 25$ .  
 7. *Selenaria maculata*, Busk, fossil,  $\times 25$ .  
 8. — *initia*, sp. nov.,  $\times 25$ .  
 9. — *maculata*, Busk, recent,  $\times 25$ .  
 10. *Smittia collaris*, var.,  $\times 25$ .  
 11. *Lunulites petaloides*. Apertures of central zoecia, closed by subsequent growth,  $\times 85$ .  
 12. *Selenaria maculata*, Busk. Diagrammatic, showing grain of sand on which it grew.  
 13. *Retepora marsupiata*, Sm. Dorsal surface.  
 14. *Smittia Napierii*, sp. nov.,  $\times 25$ .  
 15, 16. *Catenicella alata*, Thoms.,  $\times 25$ .  
 17. *Cribrilina terminata*, Waters,  $\times 25$ .  
 18. *Cellepora granum*, Hincks, var.,  $\times 25$ .  
 19. *Membranipora arethusa*, d'Orb.,  $\times 25$ .  
 20. — *lusoria*, var. *coarctata*,  $\times 25$ .  
 21. *Retepora marsupiata*, Sm.,  $\times 25$ .  
 22. *Membranipora oculata*, Busk,  $\times 25$ .

24. *On the BASALT-GLASS (TACHYLYTE) of the WESTERN ISLES of SCOTLAND.* By Prof. JOHN W. JUDD, F.R.S., Sec. G.S., and GRENVILLE A. J. COLE, Esq., F.G.S. (Read May 23, 1883.)

[PLATES XIII. & XIV.]

IN a previous paper\* it has been pointed out that the Tertiary volcanic rocks of the Western Isles of Scotland offer beautiful examples of materials of every variety of composition, from the most acid to the most basic, and of every type of structure, from the holocrystalline to the vitreous. The detailed description of these varieties of volcanic rocks was reserved for a future occasion; and in the present paper we propose to give the first of such a series of descriptions. As the more acid vitreous rocks have during recent years been discussed in considerable detail in numerous papers read before this Society, it may not be inappropriate to direct attention to the rare but equally interesting glasses of basic composition, which have, up to the present time, received far less notice in this place. The studies on which this paper is based have been carried on in the Geological Laboratory of the Normal School of Science and Royal School of Mines.

### 1. *History of Previous Opinion on the Subject.*

By the older writers on petrography rocks of the kind of which we now treat appear to have been classed as "pitchstones." Jameson and the other followers of Werner, who endeavoured to introduce the precision of nomenclature and the exact methods of their master into the study of British rocks—though they recognized these materials, not as minerals but as rocks—do not seem to have discerned the difference between the acid and basic varieties. Macculloch, who may be justly regarded as the father of British petrography, as early as 1819 pointed out that, though basalt occasionally passes into glass, yet examples of such a transition are exceedingly rare†. He particularly records two such cases in the Western Isles of Scotland. One of these instances of a transition from basalt into "pitchstone" is given as occurring in the Isle of Lamlash (Holy Isle), near Arran, and is illustrated by a detailed description and drawing‡. The other example is at Garbsbeinn, in Skye; but the specimen described was not found *in situ*§.

In 1827 Sedgwick and Murchison found a basalt dyke at the Beal near Portree, in Skye, the sides of which are seen passing into

\* Quart. Journ. Geol. Soc. vol. xxx. p. 233.

† Western Islands of Scotland, vol. i. p. 402.

‡ Ibid. vol. ii. p. 437.

§ Ibid. vol. i. p. 402.

“pitchstone;” and the fact is recorded by the latter author in the Transactions of the Geological Society\*.

In 1829 Boué† referred to the two cases of basalt passing into glass already described by Macculloch; and it was probably on specimens carried to Paris by Boué that Delesse made the interesting observations to which we shall refer in the sequel.

On the Continent, the first clear recognition of the distinction between the basic and acid glasses appears to be due to Breithaupt in 1826. Klaproth‡, it is true, had as long ago as 1807 described a “black fossil” from Guiliana in Sicily as “slaggy augite;” and this substance is now generally regarded as belonging to the class of basalt-glass; but to Breithaupt§ we owe the precise indication of those characters by which the basic glasses are distinguished from similar materials of different composition. Breithaupt regarded the substance which he obtained from the Säsebühl between Göttingen and Dransfeld as a new mineral species, and indicated its distinctive properties with great precision. He proposed for it the name of “tachylite,” signifying *the rapidity with which it undergoes fusion* || before the blowpipe. It is worthy of remark that the author of the species and his followers on the Continent down to quite recent times regarded the substances of this class as minerals and not as rocks.

In 1840 Gmelin¶ described a somewhat similar substance from the Vogelsgebirge (probably from Bobenhausen); and in 1841 Klipstein\*\* gave more precise information concerning the mode of occurrence of this material. In 1844 Hausmann†† gave a new description of the substance from the Säsebühl, accompanied by an analysis by Schnedermann; and he connects with it a tachylite-like “fossil” from the Wetterau, which Gmelin‡‡, four years before, had analyzed and referred to augite. In 1847 Hausmann§§ separated the Bobenhausen material from tachylite as another mineral species under the name of “hyalomelane,” though the grounds of this division do not very clearly appear.

\* Trans. Geol. Soc. vol. ii. p. 359. The veins of Carsaig in Mull, with which the Beal dyke is erroneously compared, are formed of a black pitchstone which is of acid composition, containing 68 per cent. of silica. A similar comparison is made by Lyell and Murchison, Edin. Phil. Journ., July 1829.

† Essai géologique sur l'Ecosse, p. 284.

‡ Beiträge zur chemischen Kenntniss der Mineralkörper, vol. iv. p. 190.

§ Kastner's Archiv für die gesammte Naturlehre, vol. vii. p. 112 (1826).

|| A great amount of confusion has taken place with respect to this name “tachylite.” It has been frequently written “tachylite,” “tachylith,” and even “trachalite.” Naumann and others state that the rock is so called from the ease with which it is decomposed by acids. A reference to Breithaupt's original memoir shows that the spelling and origin of the name are as stated in the text. The name “bottleite,” said by Kinahan to have been locally given to it, does not appear to have come into any general use.

¶ Poggendorff's Annalen, vol. xlix. p. 233.

\*\* Neues Jahrbuch für Min. &c. 1841, p. 696.

†† Studien d. göttingischen Vereins bergmänn. Freunde, vol. v. p. 91.

‡‡ Neues Jahrbuch für Min. &c. 1840, p. 549.

§§ Handbuch der Mineralogie, zweiter Theil, vol. i. p. 545.

In 1853 Sartorius von Waltershausen \* described similar substances from Iceland under the name of "sideromelane," noticing that they formed the anhydrous kernels of a material identical with his "palagonite."

In 1868 Petersen † described a glassy variety of the nepheline-basalt of the Rossberg, to which he gave the name of "hydro-tachylyte."

Zirkel, Vogelsang, Möhl, Bořický, Sandberger, and others describe different varieties of basalt-glass under the name of "tachylyte" (often misspelt "tachylite"); and by this same designation the Scottish examples were referred to by one of us in 1875 in the paper already cited. Mr. Rutley, in 1877, applied the same name to a similar rock from County Down, Ireland.

But in 1872 Prof. Rosenbusch ‡ argued in favour of restricting Breithaupt's name of tachylyte to those varieties which are easily decomposed by hydrochloric acid, and of giving Hausmann's name of hyalomelane to such as are only partially or not at all decomposed by the same agent; and this suggestion was adopted by Cohen§, Möhl||, and other writers.

In 1877, however, Prof. Rosenbusch ¶ gave up the distinction altogether, having apparently become impressed by the difficulty and uncertainty of the test of solubility in acid as applied to rocks. He was, moreover, influenced in this by the fact that, following the system already adopted by Möhl and Zirkel, he now classified these glassy products not as mineral species, but as rocks—the vitreous form of basalt.

Penck\*\*, in 1879, argued with much force in favour of adopting the same course; and the distinction between tachylyte and hyalomelane, as well as their inclusion among mineral species, may now be regarded as being by universal consent abandoned. Various names have been proposed by different authors for substances of the class, such as "glassy basalt," "vitreous basalt," "basalt-vitrophyre," "basalt-glass," and "basalt-obsidian."

In his most recently published classification of rocks††, in 1882, Prof. Rosenbusch recognizes only two divisions among the anhydrous basic glasses—basalt-glass (including tachylyte, hyalomelane, sideromelane, and slaggy augite), and hydrotachylyte or nepheline-basalt-glass.

## 2. *Distribution and Mode of Occurrence.*

Basalt-glass, though a widely distributed rock, is one which cannot be considered as by any means of common occurrence. It does

\* Über die vulkanischen Gesteine in Sicilien und Island, p. 202.

† Neues Jahrbuch für Min. &c. 1869, p. 32.

‡ Neues Jahrbuch für Min. &c., 1872, p. 148.

§ Ibid. 1876, p. 746.

|| Zusammenstellung und Beschreibung einer Sammlung typischer Basalte.

¶ Mikroskopische Physiographie, vol. ii. p. 445.

\*\* Zeitschrift der deutschen geologischen Gesellschaft, vol. xxxi. pp. 521, 568, &c.

†† Neues Jahrbuch für Min. &c. 1882, vol. ii. p. 16.



not appear to constitute great rock-masses, but is usually found as a local variation of certain types of dolerite and basalt. An exception to this rule exists in the case of the well-known glassy lavas of Hawaii; but this exception we shall discuss in the sequel.

The most general mode of occurrence of basalt-glass is as a selva (Saalband) to basaltic dykes; and this is the only condition under which we have found it to occur in the Western Isles of Scotland. Under similar circumstances it has been observed in Iceland\*, Bohemia†, and many other districts.

Other modes of the occurrence of basalt-glass which have been recorded are as follows:—Lyell and Murchison found the basaltic lava of Thueyts in the Vivarais, where flowing over gneiss, to be coated on its under surface with a band of glassy material‡. Many authors have described the surfaces of lavas and ejected blocks as covered with a glassy crust. Zirkel notices that the lava-stalactites in a cave in a basaltic lava-stream in Iceland have a surface-film of basalt-glass§; and a similar film is stated to surround the air-cavities in a basalt of Hellegrund, near Münden||. At Bobenhausen in the Vogelsgebirge and elsewhere basalt-glass is recorded as occurring in basalt in nests from the size of a walnut to that of a child's head¶. Sartorius von Waltershausen and others have described kernels of basalt-glass (sideromelane) as being abundant in the basaltic tuffs of Iceland, Sicily, and other districts; and in these cases the outside portions of the kernels are often found to graduate into palagonite\*\*. Some authors, indeed, regard all palagonite as the result of the hydration and alteration of particles of basalt-glass.

From a discussion of all the known occurrences of basalt-glass, Möhl†† has argued that it has in every case been formed by the rapid cooling of portions of basaltic lava.

Besides the two localities at which basalt-glass has been already noticed in the Western Isles of Scotland, we have only succeeded in finding it at three other points, namely Sorne Point and Gribun in the Isle of Mull and Screpidale in the Isle of Raasay. The conditions under which the rock occurs at these five known localities are as follows:—

At the Beal, near Portree, in the Isle of Skye, a basaltic dyke has glassy selvages about two inches thick. Murchison, it is true, gives the width as four inches; but we have never found it exceeding the amount stated. This is by far the most striking occurrence of basalt-glass with which we are acquainted. Its vitreous character

\* Zirkel, *Lehrbuch der Petrographie*, vol. ii. p. 303.

† Borický, *Sitzungsberichte der k. böhmischen Gesellschaft der Wissenschaften in Prag*, 1873, p. 8; also *Petrogr. Studien an den Basaltgesteinen Böhmens*, p. 182.

‡ *Edinburgh New Philosophical Journal*, April to October, 1829, p. 29.

§ *Lehrbuch der Petrographie*, vol. ii. p. 304.

|| *Ibid.*

¶ *Neues Jahrb. für Min. &c.* 1841, p. 696.

\*\* Sartorius v. Waltershausen, 'Ueber die vulkanischen Gesteine in Sicilien und Island,' 1853, p. 202.

†† *Die Gesteine der Sababurg in Hessen* (Cassel, 1871).

gradually diminishes as we trace it towards the interior of the dyke, the glassy rock merging insensibly into the basalt. We shall point out later the peculiar columnar and other joint-structures which are exhibited at this locality.

At Lamlash (Holy Isle), Arran, the mode of occurrence has been very clearly described and illustrated by Macculloch, who gives a section at the spot\*. The glassy selvage of the dyke never exceeds one inch in width; it is not so perfectly vitreous as that of the Beal near Portree, its lustre inclining more to resinous, and it merges insensibly into the basalt of the body of the dyke.

At Sorne Point, on the north-west coast-line of the Isle of Mull, a very vitreous selvage is found in a dyke that intersects the lava-streams composing the great plateau of Mishnish; it seldom exceeds one fourth of an inch in width, and passes into the basalt of the dyke by the most insensible gradations.

At Gribun, in the west of Mull, a dyke of basalt is seen by the road that leads from the village of that name to Kilfinichen, just where it emerges on the basalt-plateau; and the sides of this dyke are formed by glassy selvages never more than half an inch in thickness.

Lastly, at Screpidale, in the Isle of Raasay, one of the dykes of basalt passing through the grand precipices of Jurassic strata has also glassy sides. The actually vitreous portions of this dyke, however, are very thin indeed, forming little more than surface-films.

The only other case which we have found in the Western Isles of Scotland at all comparable to these, is the occurrence of a basic glassy rock among the later-formed products of the volcano of Beinn Shiant in Ardnamurchan. Unfortunately the specimens were not found *in situ*; and their exact mode of occurrence is therefore unknown. Prof. Jameson † and Dr. A. Geikie ‡ have described the occurrence of a "pitchstone" at Eskdale which appears to be similar in composition to the rock of Beinn Shiant. Both are probably augite-andesite glasses. From the description given of the pitchstone of Eskdale it would appear as though a columnar dyke had opened along its central plane of weakness, where the two sets of columns meet, and permitted the extrusion of material which consolidated as a "pitchstone."

In the north of Ireland some of the basaltic dykes have been described as having vitreous selvages§. The microscopic characters of one of the basaltic glasses, that of Slievenalargy, co. Down, have been described by Mr. Rutley; and it has been analyzed by Dr. Haughton||.

### 3. *Specific Gravity.*

As Delesse so long ago pointed out, the specific gravity of a rock

\* Western Islands of Scotland, vol. ii. p. 437.

† Mineralogical Description of Dumfriesshire, p. 115.

‡ Proceedings of the Royal Physical Society of Edinburgh, vol. v. p. 29.

§ Kinahan, Geol. Mag. decade ii. p. 426.

|| Journal of the Royal Geological Society of Ireland, vol. iv. p. 227.

of crystalline structure is always higher than that of a rock of the same chemical composition, but having a more or less vitreous or colloid structure. In the same way the glassy products formed by the fusion of crystalline rocks are always of less density than the rocks themselves. Delesse fused a basalt having the specific gravity of 2.85, and found the glass thus produced to have a density of 2.77. The well-known melaphyre (altered basalt) called Rowley Rag has a specific gravity of 2.84 according to our determinations; the black glass formed by Messrs. Chance, of Birmingham, from the fusion and rapid cooling of the same, we found to have a density of 2.75; the same material when slowly cooled, yielding a product full of crystals of felspar and skeleton-crystals of magnetite, has a density of 2.77.

But although the rule that the crystalline forms of rocks are more dense than the glassy is very generally true, there is, as Delesse himself pointed out\*, a remarkable exception to it in the case of a basalt-glass of the Western Isles of Scotland. Delesse found that a portion of the basalt-vein of Lamlash has a density of 2.649, while the glassy basalt forming the selvage of the dyke is *denser*, having a specific gravity of 2.714. This anomalous circumstance has been confirmed by a series of careful determinations which Mr. Thomas Davies, acting on our suggestion, has made on a specimen of this dyke in the British-Museum collection. He found that the basalt of the dyke had a specific gravity of 2.67, the part of the glassy selvage adjoining and graduating into basalt had a specific gravity of 2.72, while nearer to the side it was 2.74, and on the extreme edge 2.78.

Delesse endeavoured to explain this anomalous rise of density in the more vitreous portions of the rock by a slight difference of composition in the two parts of the mass. It is true that his analysis shows the basalt to contain a little less silica and rather more water than the glass; but the difference is so slight as to be almost within the limits of errors of analysis, and perhaps does not sufficiently explain this curious difference of density. The microscopic study of this rock shows that the basalt of the dyke is a magma-basalt, in which only incipient crystallization has taken place. It is possible that the basalt has suffered greater alteration than the more compact glass of the selvages of the dyke.

The average density of basalt-glass may probably be taken as about 2.7. Von Lasaulx gives the range as from 2.51 to 2.56 †; but this is certainly below the truth. The basalt-glass (sideromelane) of Iceland has, according to Sartorius von Waltershausen ‡, a specific gravity of 2.53; the "tachylite" of the Säsebühl has a specific gravity of 2.58 §; and the "slaggy augite" of Sicily,

\* Annales des Mines, vol. xiii. pp. 369, 370.

† Elemente der Petrographie, p. 225 (1875).

‡ Vulkan. Gesteine in Sicilien und Island, p. 203

§ Hausmann, 'Neues Jahrb. für Min.' &c. 1844, p. 70. Breithaupt (Kastner's Archiv für die gesammte Naturl. vol. viii. p. 112) gives specific gravity 2.50 to 2.54.



according to Klaproth, of 2·67\*. Möhl states that the basalt-glass of Sababurg has in its most vitreous condition a density of 2·68, and in its less vitreous of 2·76†. The density of the basalt-glass of Bobenhausen is, according to the same author, 2·71‡, and that of Ostheim 2·74§. Cohen|| records the specific gravity of six varieties from the Sandwich Islands, the average of which is 2·71.

The basalt-glass of the Western Isles of Scotland appears to be generally distinguished by its very high specific gravity. That of the Beal, near Portree, is 2·72; that of Lamlash, 2·78; that of Gribun, in Mull, 2·82; that of Screpidale, in Raasay, 2·84; while the basalt-glass of Sorne has a density of no less than 2·89. This difference appears to be connected with peculiarities of chemical composition to be hereafter noticed.

Of somewhat analogous substances we may observe that the tephrite-glass of Klein Priesen has a density, according to Bořický¶, of 2·65, the tephrite itself giving 2·696. The augite-andesite glass of Beinn Shiant, Ardnamurchan, gives 2·62, and the probably similar rock of Eskdale 2·7\*\*.

#### 4. Other Physical Properties.

The colour of the freshly broken surfaces of the basalt-glass of the Hebrides varies from velvet-black to pitch-black. The joint-planes and all exposed surfaces, however, are covered with a film of a grey or greenish-grey colour, occasionally passing into brown. This surface-film, which may be due either to chemical change or to molecular alteration of the exposed faces, appears to be analogous to what is seen in the pitchstones of Ponza, which, when freshly broken, are perfectly vitreous in appearance, but in a few seconds become coated with a delicate film which impairs their lustre††. The beautiful iridescence seen on some surfaces of the basalt-glass of the Beal, in Skye, is probably due to interference produced by a thin film of the same kind.

The lustre of the rock at the extreme edge of the dykes at the Beal, Gribun, and Sorne is perfectly vitreous; but it graduates to resinous, horny, and glimmering in passing inwards into basalt. The lustre of the Lamlash and Screpidale basalt-glass is never more than resinous.

The hardness of basalt-glass appears to be not very different from that of orthoclase, varying from 5·5 to 6·5. Though probably, as a rule, softer than obsidian, the difference is not sufficient to distinguish it readily from that rock. But, on the other hand, the hardness of basalt-glass is so much greater than that of the pala-

\* Beiträge zur chemischen Kenntniss der Mineralkörper, vol. iv. p. 190.

† Die Gesteine der Sababurg in Hessen, (Cassel) p. 40.

‡ Ibid.

§ Ibid.

|| Neues Jahrbuch für Min. &c. 1880, vol. ii. p. 41.

¶ Petrographische Studien an den Basaltgesteinen Böhmens, pp. 182 and 210.

\*\* A. Geikie, Proceedings of the Roy. Phys. Soc. of Edinburgh, vol. v. p. 253.

†† Geol. Mag. dec. 2, vol. ii. (1875) p. 308.



gonites and other hydrated materials of that class that it serves as an easy means of distinction between the altered and unaltered forms.

The whole of the basalt-glasses are strikingly magnetic. The powder of all of them is easily attracted by the magnet, those of Sorne, Srepidale, and Gribun exhibiting this character in a specially marked degree.

Basalt-glass is at once distinguished from vitreous substances of more acid composition by its easy fusibility, the product being an opaque black-brown or black bead. The fusibility of the varieties from the Western Isles appears to be little above 2 of von Kobell's scale, while that of typical obsidian is no less than 4.5 of the same scale, the product of fusion being a white enamel.

The basalt-glass from the Hebridean localities appears to be always traversed by numerous joint-planes. The most pronounced of these are parallel to the side of the dyke, and enable the glassy material to be easily separated from the basalt in thin layers. Besides these principal joints, there are usually one or two other sets at right angles to one another and to the sides of the dyke. Hence the surfaces of the dyke, where in contact with the rock which it traverses, are broken up by these joints into small rectangular areas. This character is strikingly exemplified by the basalt-glass of the Beal.

The same dyke also exhibits in some portions of its glassy selvage a remarkable columnar structure. The columns are very minute, often as thin as fine needles, about  $1\frac{3}{4}$  inch in length, and sometimes beautifully curved. Some specimens present a miniature reproduction of the celebrated Clam-shell Cave in Staffa. Occasionally the columns are as much as  $\frac{1}{8}$  inch in diameter (Pl. XIII. fig. 1).

This finely columnar structure affords an admirable illustration of the fact that the diameter of the columns in a rock is in part dependent on the coarseness of the materials of which it is composed. While the highly crystalline rocks of the Shiant Isles and Ailsa Craig form columns with a diameter of 10 or 12 feet, these vitreous rocks exhibit columns of almost microscopic dimensions.

Besides the rectangular and columnar jointing, a minutely spheroidal structure is sometimes found developed in the basalt-glass. Hence, under the microscope, it frequently exhibits traces of the well-known "perlitic" structure. This last-mentioned fact has been noticed by Zirkel in the case of the basalt-glass of Marostica (Monte Glosso) in the Euganean Halls, by Mr. Rutley in the "tachylyte" of Slievenalargy in the north of Ireland, and by Fouqué and Lévy in the lava of Graham's Isle.

#### 5. *Solubility in Acids.*

So much importance has been attached by some authors to this character, as presented by rocks of this class, that it is perhaps desirable to discuss in some detail the behaviour of the rocks now being described when subjected to the action of acid.

As we have already seen, many writers have classified the easily soluble forms as "tachylytes," and those only slightly acted on by acids as "hyalomelanes." It says little, however, for the value of this distinction, that different authors have placed the same rock in different classes when judged by this standard. Thus Möhl's conclusions concerning the solubility of the different basalt-glasses appear to be very different from those of Rosenbusch and other writers. This solubility in acids appears to depend on so many conditions, such as the more or less altered condition of the specimen, the fineness of the powder operated upon, the degree of concentration of the acid employed, the time and temperature of digestion, &c., that it is not difficult to account for these striking discrepancies. Penck, as we have already seen, has argued with much force in favour of abandoning the distinction based on solubility in acids\*; and in his later works Rosenbusch† himself appears to have entirely abandoned it.

In order to compare the behaviour of the several rocks here described under the action of acids, we submitted weighed portions of their powder to the action of concentrated hydrochloric acid for a period of ten days, boiling them each day for some time. The basalt-glass of the Beal left a residue of 81·6 per cent.; that of Sorne of 70·79; that of Gribun 83·40; and that of Lamdash 83·37‡; while the rock of Screpidale, which was even attacked by the cold acid, left a residue of only 57·82 per cent. In all cases flocculent silica was separated, but in some in much greater quantity than others.

In order to compare these results with those given by other rocks of the same class, we submitted a glassy lava of Hawaii and the artificially fused rock of Rowley Regis to the same test. The former left a residue of 50·57, and the latter of 58·7.

Treated for the same time, but with only one boiling, Mr. Grant Wilson§ found that the Eskdale pitchstone left a residue of 83·2 per cent. We have determined that in the apparently similar rock of Beinn Shiant the insoluble portion is, after daily boilings during the same period, 81·17 per cent.

Krukenberg|| found the proportions dissolved from different varieties of Hawaiian lava, which were digested in hydrochloric acid from ten to sixteen hours, to vary from 49 to 62 per cent.; while B. Silliman, jun.¶, after similar experiments, obtained as the insoluble proportion from 50 to 57 per cent. Cohen\*\*, after a

\* Zeitschrift der deutschen geologischen Gesellschaft, vol. xxxi. 1879, p. 521, &c.

† Mikroskopische Physiographie, vol. ii. p. 445 (1877), and Neues Jahrbuch für Min. &c., 1882, vol. ii. p. 16.

‡ Delesse found that, after boiling with hydrochloric acid, the glassy rock of the Lamdash dyke gave a residue of 87·7 per cent., and the basaltic central portion of 82 per cent.

§ Proc. Roy. Phys. Soc. of Edinburgh, vol. v. p. 253.

|| Mikrographie der Glasbasalte von Hawaii. Tübingen: 1877, p. 3.

¶ Memoirs of the Boston Soc. of Natural History, vol. i. p. 460.

\*\* Neues Jahrb. für Min. &c. 1876, p. 746.

digestion of a specimen in concentrated hydrochloric acid for thirty hours, found a residue of 39·62 per cent., and, with Rosenbusch, classes these Hawaiian lavas as hyalomelanes. Krukenberg, however, regards it as doubtful whether they should be placed with tachylyte or with hyalomelane.

Borický\* found the tephrite-glass of Klein Priesen to be decomposed partially and with difficulty by hydrochloric acid, some flocculent silica being separated. Many of the German basalt-glasses, on the other hand, appear to be entirely decomposed by boiling hydrochloric acid, that of the Säsebühl, according to Möhl†, after two days' digestion, and some even more readily than this.

Classified according to the test of solubility in acids, the rock of Screpidale might perhaps be placed with the tachylytes, and the Beal, Sorne, and Gribun rocks with the hyalomelanes; but our own results, like those of Rosenbusch and Penck, tend to the conclusion that it is advisable to abandon altogether a distinction founded on such an uncertain character.

### 6. *Chemical Composition.*

If, as there seems reason to believe, basalt-glass is merely a rapidly cooled portion of a basalt-lava, we may expect the two rocks to have the same chemical composition. Delesse's analysis of the dyke of Lamdash and of its vitreous selvage appears to indicate that this is really the case. The analyses are as follows‡:—

	Basalt of centre of dyke.	Basalt-glass of side of dyke.
Silica .....	55·20	56·05
Alumina .....	16·98	17·13
Oxide of iron .....	11·00	10·30
„ manganese .....	traces.	traces.
Lime .....	6·80	6·66
Magnesia .....	0·52	1·52
Soda .....	5·65 (by difference). }	3·29
Potash .....		
Water and volatile matter....	3·85	3·50
	<hr/> 100·00	<hr/> 99·43

The differences in these two results, judging by their character, are such as may be fairly supposed to fall within the limits of error in analysis.

It has frequently been pointed out, however, that the average composition of the basalt-glasses differs from that of the basalts,

\* Petrographische Studien an den Basaltgesteinen Böhmens, p. 182.

† Die Gesteine der Sababurg, (Cassel, 1871) p. 41.

‡ Annales des Mines, vol. xiii. p. 369 (1851). In the analysis of the basalt-glass as given by Delesse, the total (99·53) does not agree with the figures of the column, which amount, as above, to 99·43. A misprint may have occurred in the column itself.

the former being of more acid composition than the latter. It is conceivable that in a dyke the crystals brought up from below may be made to congregate in the central part of the mass, while its sides contain more than their due share of the fused liquid material in which these crystals are entangled. In this way, since we now know, from the researches of Rosenbusch and others, that the glassy magma of a rock is often of far more acid composition than the crystals imbedded in it, the selvages of some dykes may have a higher silica-percentage than the rock in their central portions. But that this is ever the case we have as yet no definite proof; and, as we shall now proceed to indicate, there is another and a more probable mode of accounting for the more acid composition of most basalt-glasses.

It is a well-recognized fact that the acid rocks more readily pass into a glassy condition than those of basic composition. Obsidians or rhyolite-glasses are common and widely distributed rocks; trachyte-, andesite-, and phonolite-glasses are less common; and basalt-glasses, as we have seen, are comparatively rare. This fact is probably accounted for by the circumstance, which has been recognized by chemists\*, that mixtures of silicates in which silicates of the alkalis abound more readily assume the vitreous condition than those in which silicates of lime, magnesia, iron, and alumina predominate; and the acid rocks usually contain a large proportion of the silicates of the alkalis.

Now, such being the case, we might expect that among basic rocks, like basalts, those varieties would be more likely to assume a glassy condition in which the silica-percentage is high, especially if the proportion of the alkalis at the same time were excessive.

A comparison of the various analyses of basalt-glass, such as those brought together by Möhl†, Zirkel‡, and others, shows this to be the case, the percentage of silica in these rocks being seen to vary from 50 to more than 56. The proportion of the alkalis is in most cases considerably in excess of what is commonly found in basalts, varying from 3 or 4 to 10 or 12 per cent. The quantity of water in basalt-glass appears to be small and variable; its presence may probably be regarded as accidental. In this respect basalt-glass strikingly differs from the palagonites, which contain from 11 to 25 per cent. of water. The rock known as hydrotachylite, which is regarded by most petrographers as a nepheline-basalt glass, contains, it is true, nearly 13 per cent. of water, according to the analysis of Petersen§. Possibly, however, this rock must be considered to some extent a product of alteration, as was believed by Möhl||.

We may perhaps conclude that as a general rule the basalts which show a tendency to assume the vitreous condition are those

\* Miller, *Elements of Chemistry*, part ii., 5th edition, p. 416 (1874).

† *Die Gesteine der Sababurg in Hessen*, (Cassel) p. 41.

‡ *Lehrbuch der Petrographie*, vol. ii. p. 305.

§ *Neues Jahrbuch für Min. &c.* 1869, p. 32.

|| *Die südwestlichen Ausläufer des Vogelsgebirges*, Theil 1, p. 21.



with a high percentage of silica and an unusually large proportion of the alkalis.

The basalt-glass of the Beal near Portree seems to be an illustration of this rule, as does the similar rock of Lamlash, Delesse's analysis of which has been already cited. An analysis of the Beal rock, made in Dr. Frankland's chemical laboratory, under the superintendence of Dr. Hodgkinson, F.I.C. &c., was as follows:—

Silica .....	52.59
Alumina .....	17.33
Ferric Oxide .....	11.14
Manganous Oxide .....	0.66
Lime .....	6.47
Magnesia .....	2.62
Soda .....	4.24
Potash.....	2.40
Loss on ignition .....	3.27

---

100.72

Traces of copper and barium were also detected in this rock. The high percentage of silica and the large proportion of the alkalis are especially noteworthy in this analysis.

But certain of the varieties of basalt-glass found in the Western Isles of Scotland are especially interesting to the petrographer, as showing that even the basalts with a low percentage of silica do sometimes, though rarely, pass into the vitreous condition.

We have already pointed out that the varieties of basalt-glass of Gribun in Mull, Srepidale in Raasay, and Sorne in Mull, differ from those of the Beal in Skye and Lamlash near Arran by their high specific gravity. The density of the three first-named rocks is 2.82, 2.84, and 2.89 respectively, and that of the two last-named 2.72 and 2.78. All the foreign basalt-glasses recorded have densities ranging from 2.5 to 2.7. It became therefore a matter of interest for us to determine whether these exceptionally dense basalt-glasses of the Western Isles of Scotland were not vitreous forms of more basic basalts than had yet been found in this condition.

Mr. J. J. H. Teall, F.G.S., has kindly undertaken the partial analysis of these interesting materials; and his results are quite in accordance with our anticipations. Mr. Teall's analyses show that the basalt-glass of Gribun in Mull contains 50.51 per cent. of silica and 10.05 of metallic iron, the basalt-glass of Srepidale in Raasay contains 46.68 per cent. of silica and 10.80 of metallic iron, and that of Sorne in Mull 47.46 of silica and 12.47 of iron. It is evident that the exceptionally high specific gravity of the last-mentioned rock is due to the large quantity of the oxides of iron which it contains.

The only basalt-glass which has been hitherto described with a composition approaching that of the Scottish rocks is the siderome-

lane of Iceland, which has 49 per cent. of silica. Its specific gravity, however, is given by Sartorius von Waltershausen\* as 2.531. This low density is the more remarkable when we find that the proportion of oxide of iron is above 20 per cent., and that there is little or no water in the rock. If this determination of the specific gravity be correct, it would appear that this sideromelane differs in a very marked manner from the ordinary basalt-glasses.

While we have proof in these very basic glasses of Scotland that even basalts with a low percentage of silica sometimes assume the vitreous form, yet it is at the same time made evident that the tendency to do so diminishes as the silica-percentage declines. The basic glasses of Sorne, Screpidale, and Gribun form much narrower selvages to the dykes than the more acid ones of the Beal and Lamlash.

The vitreous rock of Beinn Shiant, which contains 58.67 per cent. of silica, is, judging from its composition, probably like that of Eskdale, not a true basalt-glass, but an augite-andesite-glass. Similar vitreous conditions of augite-andesite have been described by Fouqué and Lévy † from Santorin, and by Cohen ‡ from between New Britain and New Ireland, this latter being a pumiceous variety. Cohen also refers a Sandwich-Island rock, showing remarkable effects under polarized light due to internal strain, to the pumiceous condition of augite-andesite-glass §.

In the Sandwich Islands, as we have already pointed out, we find a striking exception to the rule that basalt-lavas only assume the glassy condition locally and as the result of rapid cooling. In those islands the whole mass of lava-streams appears to frequently consist of basalt-glass.

If the older analyses of J. C. Jackson, B. Silliman, jun., and other American chemists were to be relied upon, the exceptional characters of these Sandwich-Island rocks would seem to be sufficiently explained by their peculiar composition. According to these analyses, the Hawaiian lavas contain a proportion of silica varying from 39 to 52 per cent.; the proportion of alumina is small, and that of iron very great, sometimes from 17 to 33 per cent.; while the percentage of the alkalies is often very high indeed, occasionally over 20.

But the more recent investigations of Cohen || have suggested grave doubts as to the reliability of these older analyses. The analyses of six glassy lavas from the Sandwich Islands have given Cohen, Wagner, and van Werveke closely concordant results, the average composition of these rocks being, according to their analyses, as follows :—

\* Vulkan. Gesteine in Sicilien und Island, p. 203.

† Minéralogie Micrographique, pl. xxxv. fig. 3.

‡ Neues Jahrbuch für Min. &c. 1880, vol. ii. p. 37.

§ Ibid. p. 38.

|| Neues Jahrb. für Min. &c. 1880, vol. ii. p. 41.

Silica .....	51·71
Alumina .....	11·44
Oxides of iron.....	12·62
Lime .....	10·75
Magnesia.....	7·59
Potash.....	0·67
Soda .....	3·47
Water .....	0·98

This result is in such close agreement with the average composition of common or felspar basalts that we cannot hesitate to regard these lavas of the Sandwich Islands as referable to "basalt-glass."

Another very interesting discovery of Cohen's is the fact that a lava of Niuafoou in the Friendly Islands has a glassy structure, and a composition almost identical with that of the Sandwich-Island lavas \*. While, then, basalt-glass is, on the European continent and in North America, confined to small and local occurrences, as the selvages of dykes, the small fragments thrown out of volcanic vents and cooled rapidly in passing through the air, &c., we have in the Sandwich Islands, and perhaps also in the Friendly Islands, examples of glass of the same composition as basalt constituting the whole mass of lava-streams.

The basalt-glass of the Pacific Islands differs, however, from that of Europe by being clear and transparent. In this respect it agrees with the fused Rowley Rag and similar artificial products, in which the iron is united with the silica, and is not separated in the form of magnetite, the reverse being so very commonly the case in the locally-developed basalt-glass of Europe.

The lavas of the Sandwich Islands appear to be no less peculiar and exceptional in their behaviour during ejection. Their extreme fluidity permits of their being thrown into fountains 400 or 500 feet in height (a circumstance nowhere witnessed in the case of ordinary basalts), and of their being drawn out by the wind into the delicate threads known as Pélé's hair.

All these facts point to the conclusion that the Hawaiian lavas are ejected at a much higher temperature than that at which the basalts of Europe and North America issued. The only mineral, indeed, in the Hawaiian glassy lavas which is not fused appears to be olivine. In this peculiarity of their lavas the great Pacific volcanos present another and most interesting exceptional feature in addition to many which have been already pointed out.

### 7. *Microscopical Characters.*

The microscopical characters of many varieties of basalt-glass have been described by Zirkel †, Vogelsang ‡, Möhl §, and other

\* Neues Jahrb. für Min. &c. 1880, vol. ii. pp. 36 and 41.

† Untersuchungen über die mikroskopische Zusammensetzung der Basalt-gesteine, p. 182.

‡ Die Krystalliten, p. 111.

§ Die Gesteine der Sababurg in Hessen, (Cassel) 1871.

writers. These rocks are all found to consist of a glass, usually of a brownish colour, but occasionally colourless or greenish, in which various crystallites are distributed.

Basalt-glass, even in its most vitreous varieties, is very rarely clear and transparent. Usually opaque inclusions are so abundant as to render the rock non-translucent. In most cases it is only by the most careful grinding of slices of the rock that it is possible to obtain sections sufficiently thin to exhibit its internal structure, and it is necessary to employ the most powerful sub-stage illumination to transmit light through them at all.

In their great opacity the natural varieties of basalt-glass differ very strikingly from the artificially fused basalts, such as Rowley Rag. These artificial glasses are clear and of a rich yellowish-brown colour by transmitted light; and only faint traces of a "globulitic" structure can be made out in them with the highest powers of the microscope.

Some of the German varieties of basalt-glass, for example those of Bobenhausen and the Sababurg, have spaces of a similar clear brown glass, the crystallites being collected into skeleton crystals or spherulites; but in all the British varieties we have studied such spaces of clear glass are rare, and all these rocks are characterized by their great opacity. Indeed, in the most perfect specimens of our natural basalt-glasses, devitrification appears to have gone so far as to have resulted in the separation of the whole or nearly the whole of the magnetite, the minute crystallites of which, scattered through the rock, render it perfectly opaque, even in the thinnest slices which it is possible to prepare. Fortunately this dust of magnetite is occasionally collected into nebulous masses (cumulites), and in the more devitrified varieties into skeleton crystals; in such cases the nature of the intervening glass spaces can be made out.

The structures found in these basic glasses appear to be quite similar to those which have become so familiar to geologists from the study of obsidians, pitchstones, and the glassy varieties of the acid class of rocks. In some cases the crystallites and microliths exhibit the parallel arrangement characteristic of the banded and fluidal structures; in other cases the crystallites are united to form various kinds of skeleton crystals, or the globular and often concentric concretions known as spherulites. Sometimes the glass is traversed by numerous fine cracks, some of which are curved and concentric, giving rise to the well-known perlitic structure. Perlitic basalt-glass has been already described by Prof. Zirkel from Marostica in the Euganean Hills\*, by Mr. Rutley from Slievenalargy, county Down†, and by Fouqué and Lévy from Graham's Isle‡.

The basalt-glass of the Western Isles of Scotland is usually, to a

\* Zeitschr. d. deutschen geol. Gesellschaft, vol. xix. p. 776; also Rosenbusch, Neues Jahrb. für Min. &c. 1872, p. 141.

† Journ. Roy. Geol. Soc. of Ireland, vol. iv. p. 227.

‡ Comptes Rendus, 1878, March 25.



greater or less extent, porphyritic in structure. Basalt-lavas consist, as is well known, of a number of perfectly formed crystals of augite, olivine, felspar, and magnetite, entangled in a mass of uncrystallized material. These included crystals have probably been formed at great depths below the surface. After the extrusion of the lava, and as it slowly cools, crystals of the same minerals become more or less completely developed in the entangling magma. Careful study of such rocks, as Lévy and Fouqué have so well shown, enables us, in most cases, to clearly distinguish those crystals which have been formed at considerable depths from such as have separated from the magma, near or at the surface, during the cooling of the lava.

The crystals formed at great depths in the earth are usually larger and more perfectly developed than those separating from the glassy magma during its cooling, and they often contain liquid-cavities and enclose other crystals. Moreover they are frequently broken and rounded at their edges, and have suffered great corrosion by being partially melted-up and having their substance absorbed into the glassy magma. This glassy magma often sends prolongations of its substance into such crystals, which are, indeed, sometimes completely honey-combed by these extensions of the glassy mass\*.

The facts described point to the conclusion that crystals formed under great pressure in the midst of a fused magma may, on the relief of that pressure, be attacked and dissolved by the magma in which they were originally developed.

Many of the basalt-glasses of the Western Isles of Scotland furnish examples of porphyritically imbedded crystals, these being, in all cases, of the same kind as are found in the basalts with which the glasses are connected. Olivine and magnetite are the most abundant of these porphyritically imbedded crystals; but augite and sometimes felspar also occur (Pl. XIII. fig. 2).

The basalt-glass of the Beal, near Portree in Skye, exhibits very interesting examples of olivine and felspar crystals, the latter much corroded and eaten into by the glassy magma (Pl. XIII. fig. 3). The rock of Lamlash contains large and well-developed crystals of both felspar and augite, much broken and rounded (Pl. XIII. fig. 6). The other varieties in the Scotch area appear to contain only porphyritic crystals of olivine, much decomposed; and in some cases these are apparently rare.

All the basalts which have vitreous selvages appear to be of the class which contains a large amount of glassy residuum between the crystals; and some of them may in fact be classed as magma basalts. In certain cases, indeed, they appear to have little or no individualized felspar, and may be grouped with the Limburgites of Rosenbusch.

The most perfectly vitreous type of these rocks, which is exemplified by the extreme edges of the selvages in the Beal dykes, exhibits only the merest embryonic crystallites scattered through

\* Similar instances of corrosion are familiar among the porphyritic crystals occurring in acid rocks such as rhyolites, pitchstones, and obsidians.

the mass of brown glass. These crystallites appear, with the highest power of the microscope, as excessively minute globular bodies (globulites), which in some parts of the mass are crowded together into cumulites, leaving other parts comparatively clear and transparent (Pl. XIV. fig. 1). Sometimes an approach to a linear arrangement can be detected in these globulites. The cloudy masses exhibit in some cases the parallel grouping characteristic of the banded or fluidal structure.

In the basalt-glass of Lamlash this linear arrangement of the globulites is much more strikingly exhibited than in that of the Beal in Skye. Here we sometimes find the resemblance to strings of pearls which has led to such objects being called "margarites." Some of the globulites are seen to be transparent bodies; and this is beautifully shown by the Lamlash rock (Pl. XIV. fig. 2).

The basalt-glass of Sorne, Screpidale, and Gribun shows a further development of the embryo crystals. The fine globulites are seen to be collected into skeleton crystals quite similar in form to those found in so many slags, but usually of much smaller dimensions.

In addition to these, we find in the Screpidale rock abundant transparent colourless rod-like bodies (belonites), and in that of Gribun curious examples of forms intermediate between skeleton crystals and spherulites, which occur in the Hawaiian lavas, and have received from Krukenberg\* the name of "chiasmoliths."

As to the nature of the crystals which are thus found in an embryonic and partially developed condition in these glasses, much discussion has taken place. The minute opaque forms, which seem to have the symmetry of the cubic system, can scarcely be other than magnetite; but the larger and more transparent forms, such as are seen, for example, in the chiasmoliths, appear to be augite, while the belonites are probably for the most part felspar. The margarites in the Lamlash rock may not improbably be felspar crystals in their earliest stage of development.

Spherulites occur in the rock of the Beal, and also in the somewhat similar rock (augite-andesite-glass) of Beinn Shiant, Ardnamurchan.

In some cases, as in that of the Beal near Portree, the change from an ordinary basalt which occupies the centre of the dyke to the glass at its sides can be traced step by step. The porphyritic or first-formed crystals are alike in both the basalt and the glass, and consist mainly of olivine and felspar, the latter much rounded and corroded by the action of the glass upon it. In the glass at the extreme edge of the dyke the globulitic dust, occasionally collected into cumulites, fills the whole mass; nearer the centre this glass has the globulites united into skeleton crystals of magnetite. The basalt near the glass contains a very large quantity of unindividualized glass, in which transparent microliths of felspar and augite can be made out under a high power. In the basalt of the centre of the dyke the felspar, augite, and magnetite are well

\* *Mikrographie der Glasbasalte von Hawaii*, p. 8 and fig. 30.

crystallized, but a large amount of glass of a brownish or greenish colour is seen between the crystals (Pl. XIII. fig. 7; compare fig. 8 and Pl. XIV. fig. 1).

In the Lamlash basalt-glass the crystallites of magnetite, and probably of some other minerals, are numerous, and the basalt is only slightly more devitrified than the glass. This basalt is a true magma-basalt or limburgite, with porphyritic crystals of augite, olivine, and plagioclase felspar.

### 8. *Summary of Results.*

From the foregoing descriptions it will appear that in the Western Isles of Scotland we have examples of a somewhat rare class of materials of considerable interest to the petrographer.

These materials, though often classed as mineral species, are really rocks, and, indeed, constitute merely a local condition of certain types of basaltic lava. The names tachylyte and hyalomelane, as applied to mineral species, ought therefore to be abandoned altogether. The supposed distinction between tachylyte and hyalomelane, founded on their behaviour with acids, altogether fails in practice as a means of discrimination between the different varieties.

Of the several names proposed for the rocks of this class, that of "basalt-glass" appears to us to be the most convenient and least open to objection. This name indicates its mode of origin and its relation to basalt, and the only possible source of error which we can anticipate from its use is its confusion with the glassy magma, or uncrystallized residue, found in many basalts—a substance which may be of totally different composition. We would advocate in the same way calling the glassy varieties of other rocks by similar names, as rhyolite-glass, trachyte-glass, andesite-glass, phonolite-glass, &c., the names of obsidian and pitchstone or retinite being still used for the types with vitreous and resinous lustre respectively, and the terms spherulite-rock, perlite, pumice, &c. being applied to varieties exhibiting special modifications of structure. Tachylyte may, in the same manner, be a useful alternative name for the basic glasses, to be employed in contradistinction to obsidian or acid glass; but there seems to be no reason for the retention of the term hyalomelane.

From the glasses of more acid composition basalt-glass is at once distinguished by its higher specific gravity. While ordinary obsidians (rhyolite- and trachyte-glass) have a density varying from 2.3 to 2.5, the average being 2.4 or under, the density of basalt-glass varies from 2.5 to 2.9, the average being 2.7. The basalt-glass of several Scotch localities is of exceptionally high density, between 2.8 and 2.9. The glass, when unaltered, is probably in all cases of less density than the same material in a more crystalline condition.

The striking magnetic properties of basalt-glass enable us to distinguish it from other vitreous rocks, as does also its remarkable opacity even in the thinnest splinters. Perhaps the most noticeable



and distinctive of all its characters, however, is its easy fusibility and the nature of the product resulting from its fusion.

The hardness of basalt-glass is perhaps generally rather less than that of the obsidians; but the difference is not sufficiently great to afford a ready means of distinction between these two types of rocks, though it may serve to distinguish basalt-glass from the hydrated substances and altered forms known as palagonite, which are sometimes confounded with it.

In chemical composition basalt-glass agrees with the rock, of which it is, in all cases, merely a local variation. The proportion of silica varies from 45 to 55 per cent., just as in the basalts; but those forms of basalt with the higher proportion of silica appear most frequently and most readily to assume the vitreous condition. The varieties of basalt containing an exceptionally large quantity of silicates of the alkalis seem also to pass more easily into glass than any other.

In their microscopic character the basalt-glasses appear to be generally distinguished by their great opacity. When cut into sections sufficiently thin to be transparent, the abundance of crystallites and skeleton crystals of magnetite serves at once to distinguish them from the obsidians. Like other vitreous rocks, they frequently exhibit the porphyritic, the pumiceous, the banded, the fluidal, the spherulitic, and the perlitic structures.

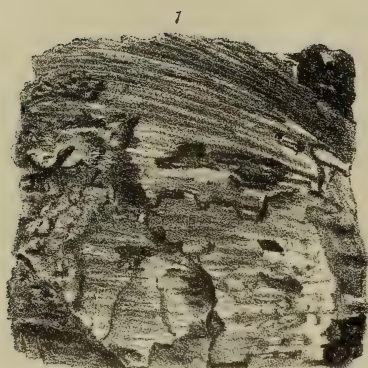
In the Western Isles of Scotland basalt-glass has only been found as a selvage to dykes of basalt. In other districts, however, it has been observed in various situations where rapid cooling has taken place, as in fragments ejected from volcanic vents, and the surfaces of basaltic lava-streams.

[*Note, July 12, 1883.*—During the discussion on the foregoing paper, and subsequently, our attention has been directed to several examples of similar materials occurring in different parts of the Western Isles of Scotland. Professor T. G. Bonney, F.R.S., has very kindly placed in our hands, for the purpose of study, a glassy material forming a selvage less than half an inch in width to a dyke which is seen near the stable in the Castle grounds at Brodick in the island of Arran. This appears to be a true basalt-glass; it has a specific gravity of 2.83, and a silica percentage of 53.96. In its microscopical characters the rock very closely resembles the basalt-glass of the Beal in Skye. Treated in the same way as the other specimens, 83.69 per cent. of the rock was dissolved in hydrochloric acid. It is very fusible, and its powder is strongly magnetic.

At the time when our paper was written we had not seen Professor Heddle's analysis of and notes on a Tachylyte from the Quiraing in Skye (*Min. Mag.* vol. v. p. 8). In an erratum to this article, published with Part 23 of the *Min. Mag.*, the same author calls attention to a very interesting note on the basalt-glass of the Beal in Skye, published by Necker in 1840 (*Edinb. Phil. Journ.* 2nd ser. vol. xxix.), wherein the true nature and properties of the material are very clearly defined.

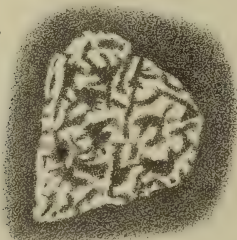






x 2

3



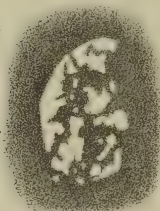
x 15

4



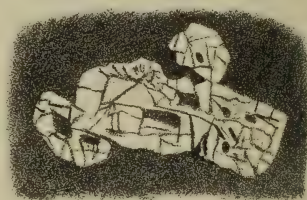
x 15

5



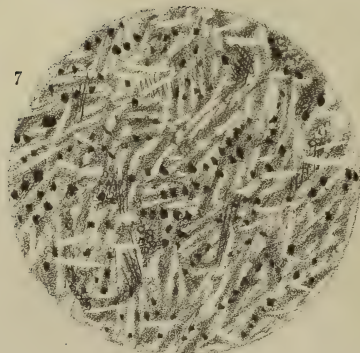
x 15

6



x 10

7



x 75

8



x 75

GAJ. Cole del. M.P. Parker lith.

Hanhart imp.

BASALT-GLASS.

## EXPLANATION OF THE PLATES.

## PLATE XIII.

Fig. 1. Portion of selvage to the basalt-dyke of the Beal, near Portree, Skye, natural size, showing the finely columnar structure exhibited by the basalt-glass of this locality. The most glassy portion of the rock, forming the outside of the dyke, lies to the left of the figure.

Fig. 2. Slice of the basalt-glass of Lamlash, Arran, magnified two diameters, and exhibiting the marked porphyritic character of the rock. The glass is perfectly black and opaque, as is always the case except in sections of extreme thinness; and the enclosed crystals are those of felspar, augite, and olivine, the latter much decomposed.

[Figs. 3, 4, 5, 6 illustrate the corroded, rounded, and fractured condition of the crystals contained in the basalt-glasses and the magma basalts which they accompany in the Western Isles of Scotland.]

Fig. 3 is a felspar crystal from the basalt-glass of the Beal in Skye.  $\times 15$  diameters.

Fig. 4. An augite crystal in the basalt of the dyke to which the last-mentioned rock forms a selvage.  $\times 15$  diameters.

Fig. 5. A greatly corroded crystal of felspar from the same rock as fig. 4.  $\times 15$  diameters.

Fig. 6. A group of felspar crystals from the basalt-glass at Lamlash, showing rounding and fracturing.  $\times 10$  diameters.

[Figs. 7 and 8 illustrate the characters of the magma-basalt dykes which pass into basalt-glass in the Western Isles of Scotland.]

Fig. 7 is taken from the centre of the dyke at the Beal, near Portree, in Skye, and is an ordinary basalt with a large proportion of glassy base.

Fig. 8, taken from near the outside of the same dyke, contains much more glassy material, the substance of the felspar being almost wholly uncrystallized. The passage from the rock shown in fig. 7 to that represented in fig. 8, and again into the glass illustrated in Plate XIV. fig. 1, is of the most insensible character.

## PLATE XIV.

[On this Plate are placed for comparison drawings made from exceedingly thin sections of five of the varieties of basalt-glass of the Western Isles of Scotland, viewed with a magnifying-power of about 500 diameters. Beside them is placed, for comparison, an example of the clear brown glass of Hawaii, viewed with the same objective.]

Fig. 1 is the basalt-glass of the Beal, in Skye. In it the magnetite dust is simply collected into cloudy patches (cumulites), leaving clearer spaces of the dark brown glass between them.

Fig. 2 is the basalt-glass of Lamlash, Arran. In this rock the minute crystallites are collected into linear series forming beaded rods similar to the structures which have been called "margarites."

Fig. 3, the basalt-glass of Screpidale, in Raasay, exhibits a more perfect separation of the crystallites of magnetite, the skeleton crystals thus formed resembling, except in their much smaller size, the forms found in many iron slags. Around each skeleton crystal an area of colourless glass is produced by the abstraction of the iron oxides.

Fig. 4. In this basalt-glass, from Sorne in the Isle of Mull, the separation of the magnetite in the form of skeleton crystals is more complete, and the forms of some of the transparent crystals are beginning to appear.

Fig. 5. In this rock (the basalt-glass of Gribun, in Mull) we find that, in addition to the perfect separation of magnetite in skeleton crystals, the formation of transparent crystallites (belonites) has gone on to a considerable extent.

Fig. 6. A glassy lava from Hawaii, consisting of a clear brown glass with a little cloudy material in parts, and a few crystallites. Some of these latter resemble the central portions of the structures to which Krukenberg gave the name of "chiasmoliths."

### DISCUSSION.

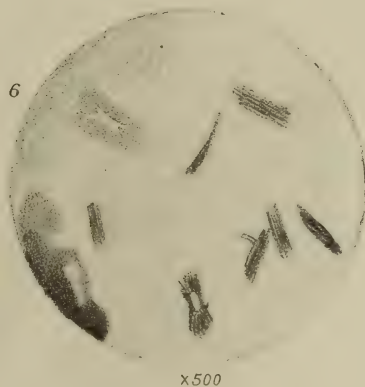
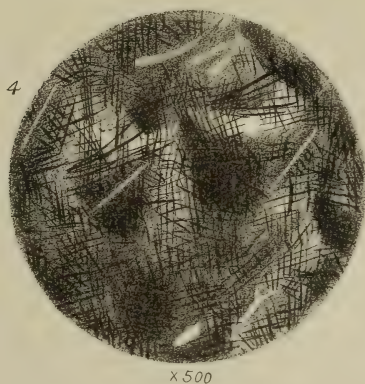
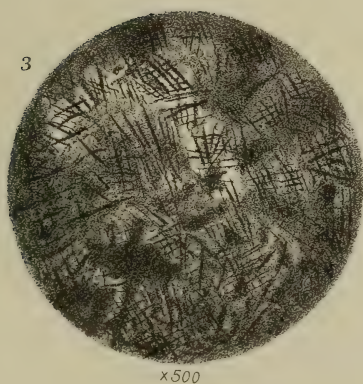
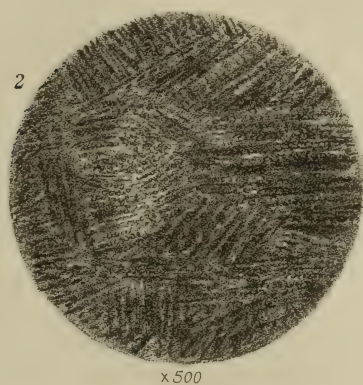
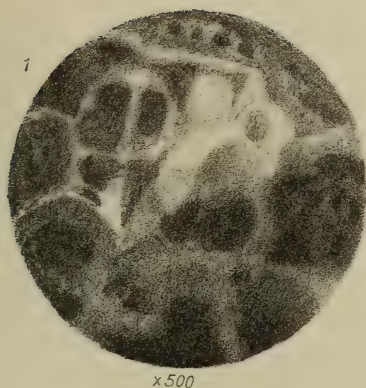
Professor BONNEY expressed his sense of the value of the paper. Students of British petrology would be much indebted to the authors for this exhaustive notice of so interesting and rare a rock. As a proof of its rarity, he said that he had examined numerous basalt dykes in Scotland and elsewhere before he found a satisfactory specimen of tachylite; and that, by a fortunate accident, appeared to be in another locality. It was by the road to Goatfell from Brodick, in Arran, at the back of the outbuildings of the Castle. Two veins of compact basalt, about 1 foot thick, intrusive in an older decomposed basalt, had an edging of tachylite from  $\frac{1}{2}$  inch to 1 inch thick. As regards the Sandwich-Island lavas, he believed that the masses of tachylite were especially connected with Kilauea (for ordinary basalts were common in the islands); might this be due to the exceptional condition of the lava in the crater of Kilauea, such an enormous mass of molten material?

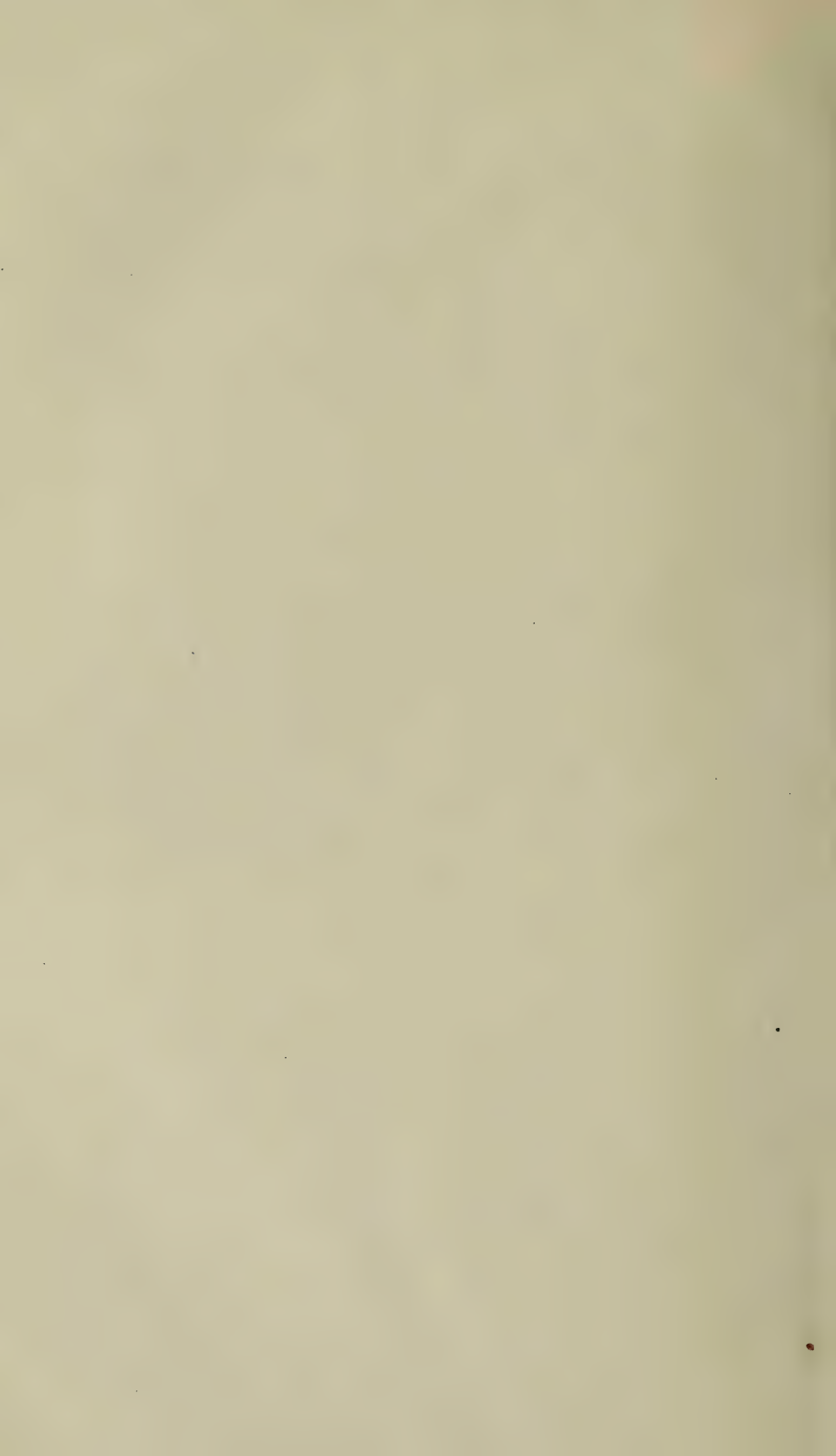
Mr. TEALL stated that the comparative rarity of basalt-glass in nature appeared somewhat remarkable when the readiness with which basalt can be fused and made to assume the condition of glass by rapid cooling is taken into consideration. He suggested that the apparent anomaly might be due to the lower fusibility of the basic as compared with the acidic material. The lower fusibility necessarily involved a greater prolongation of the time during which the conditions were favourable to crystal-development. The formation of basalt-glass on the large scale in Hawaii might be due to the fact that the material before being ejected is cooled throughout its mass by convection-currents almost to the point of consolidation before being erupted as lava. According to this view the average temperature of emission of the glassy lavas of Hawaii would be less than that of a lava cooling to normal basalt.

With regard to the crystals referred to by the author he thought that the honeycomb-structure might in part, at any rate, be due to the mode of crystal-growth.

Mr. BAUERMAN expressed the satisfaction which the paper had given him. The analysis of the Beal rock indicated a remarkably large proportion of alkalies. He had recently investigated a case of the formation of crystalline silicates and aluminates in a slag by the action of blast-furnace gas containing alkalies and oxides of zinc and manganese upon the firebricks of a hot-blast stove. The high density of the basalt-glass was probably due to separated magnetic oxide of iron. The structure, when seen under a high







magnifying power, was analogous to that of certain iron-furnace slags, which also vitrified at the edges. He thought the imperfections of the crystals due to enclosures of glass in their formation rather than to subsequent corrosion.

Mr. W. MUIR spoke of the rarity of tachylite, and said that the dykes could not have run for a long time; if the glass occurred, it would be a sign of rapid cooling.

Prof. SEELEY asked how those basalt-glasses of Scotland differed from those of the basalts of Europe which differed chemically and mineralogically from them. The Sandwich-island glasses were very rich in iron. Might the greater abundance of the glass be attributed to the iron or to the rate of motion? He called attention to the fact that the basalt-glass of the Sandwich Islands adhered to the branches of trees without scorching them.

Mr. KOCH said that he had found a tachylite in Skye, and near the leaf-beds in Mull; it occurred in bean-shaped masses and strings, generally of great thinness. He had made experiments in Siemens's furnaces. He found that slag was partly affected by the amount of moisture contained; and this was confirmed by experiments with slag. If run into moist sand, the lower part of the slag was glassy. He therefore attributed the glassy condition to the action of steam. If one slag was poured on another, a glass would be produced at the point of junction. At the Sandwich Islands he thought that the basalt was at a very high temperature. The opaque glass was formed at the lower temperature in experiments. In experiments with crystals dropped into molten slag the edges were fused.

Prof. JUDD said that similar glassy lavas flowed from Mauna Loa and Kilauea; so there did not seem to be any special reason for assigning the glassy state of the lavas to the peculiar conditions at the latter crater. He thought it more probable that the forms in the crystals were due to corrosion than to inclusion. A high percentage of alkali was common to several of the basalt-glasses of Germany. The question of the composition of the basalt was discussed in the paper. Cohen, however, had proved that there were glassy lavas identical in composition with true basalts. The rock Mr. Koch had found had not been proved to be a true basalt-glass. The quantity of moisture varied much in analysis, and truly vitreous rocks, like obsidian, seemed to be less rich in water than subvitreous ones, such as pitchstones.

25. *On a Group of MINERALS from LILLESHELL, SALOP.* By C. J. WOODWARD, Esq., B.Sc., F.G.S., Lecturer on Chemistry and Physics, Birmingham and Midland Institute, Birmingham. (Read May 9, 1883.)

THE Carboniferous Limestone at Lilleshall has for very many years been worked, partly as a flux for iron-smelting, partly as a source of lime for agricultural purposes.

Various workings in the neighbourhood have, from influx of water, been abandoned; and there remains now but one mine, known as Stump Leasow\*. It is situated by the canal, near a spot marked "Old Farm" on the one-inch Survey map.

There are two distinct beds of limestone, known as White and Grey, lying one above the other, separated by a distance of 40 yards.

The upper bands of the lower bed, or grey, are full of vertical joints, which in many cases, speaking from memory, run from six inches to a foot in width. It is in these joints that the minerals occur.

I have met with the following mineral species, put approximately in the order of frequency or abundance, commencing with the least frequent:—

Quartz.	Hæmatite.
Erubescite.	Barytes.
Copper pyrites.	Calcite.
Iron pyrites.	Dolomite.

*Quartz* is extremely rare. I have, in fact, met with but one minute crystal. It showed under the microscope both prismatic and pyramidal faces.

*Erubescite*. Only a few minute patches in the massive form have been met with.

*Copper Pyrites* is met with occasionally. It occurs in more or less defined spheroids. One specimen has a peculiar radiated structure.

*Iron pyrites* is not by any means common. It occurs in radiating masses of from  $\frac{2}{3}$  to  $1\frac{1}{2}$  inch diameter, showing faces of the cube, octahedron, and other forms. I have one specimen of the decomposed iron pyrites, which in old mineralogical books is called "hepatic pyrites." This hepatic pyrites is in cubes and octahedra.

*Hæmatite*. Occurs in minute chocolate-coloured semiglobular masses, made up of extremely minute crystals, also in an almost continuous film, coating the calc-spar and other crystals with a coppery sheen. In some cases the cavities containing minerals have the hæmatite much more thickly deposited on the surface

\* I have just learned that this mine is now closed in consequence of the expiration of the Lilleshall Company's lease.



lying lowest in the stone; but I have not satisfied myself that this is general.

*Barytes*.—Occurs in pink, lamellar, somewhat radiating masses, which cleave easily parallel to the 001 and 110 planes of Miller. At their free surfaces transparent crystals are developed, having the forms 001, 110, and 101. Besides this mode the barytes also occurs in small transparent crystals ( $\frac{1}{2}$ – $\frac{3}{4}$  inch long). The prisms are chisel-ended, being terminated by the planes 110 and  $\bar{1}\bar{1}0$  of Miller, while the sides of the prisms are contained by the forms 001 and 012.

*Calcite*.—In the uppermost bed, called by the miners “cockles,” this mineral occurs in clustered groups of crystals, each crystal being a steep scalenohedron with a rhombohedral summit. The grouping commonly takes the form of a steep three-faced pyramid. The faces of the rhombohedral summits are striated in the direction of a line bisecting the angles formed by the edges of the rhombohedron. Some attempts were made to determine these faces; but the striations prevented any satisfactory measurement. The clustered crystals of calcite have a beautiful ice-like appearance.

Some of the calcite in large masses has a pink colour, due to manganese. A portion of this pink calcite yielded

Manganous oxide (MnO) . . . . .	1·20 per cent.
Ferrous „ (FeO) . . . . .	·36 „

The calcite also occurs in more or less spherical cavities in the lowest bed of stone; and these invariably contain the mineral in pointed scalenohedrons (Dog-tooth spar).

*Dolomite*.—Is the most interesting mineral of the group. It occurs in nodules, which are apparently made up of a succession of laminæ of varying diameters. These laminæ crystallize at their edges in minute rhombs with curved faces, resembling pearl-spar. The substance of the nodule is cream-colour, but the crystalline surface is often brown from oxidation.

The minute rhombs do not admit of measurement. Two samples of the typical nodules freed from calcite were analyzed.

	1*. Sp. gr. 2·95.	2†. Sp. gr. 2·92.
Carbon dioxide (CO <sub>2</sub> ) . . . . .	42·29	44·00
Ferrous oxide (FeO) . . . . .	21·49	12·51
Manganous oxide (MnO) . . . . .	1·02	2·08
Lime (CaO) . . . . .	29·06	34·35
Magnesia (MgO) . . . . .	5·96	7·64
	99·82	100·58

\* 1 contained ·07 per cent. silica not included.

† 2 is the mean of two analyses of the same sample, in which the following were the differences from the mean :—CO<sub>2</sub> 0·13, FeO 0·17, MnO 0·06, CaO 0·14, MgO 0·00.

Calculated into carbonates, these give

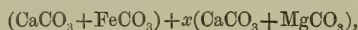
	1.	$\alpha$ .	2.
Calcic carbonate ( $\text{CaCO}_3$ ) .....	51.89	47.59	61.34
Ferrous carbonate ( $\text{FeCO}_3$ ) .....	34.62	34.74	20.15
Manganous carbonate ( $\text{MnCO}_3$ ) ...	1.65	2.13	3.37
Magnesian carbonate ( $\text{MgCO}_3$ ) .....	12.52	13.73	16.04
	100.68	98.19	100.90

No. 1 approximates in composition to a specimen of ankerite from Admont, Styria, given in Rammelsberg's 'Handbuch,' and put by Bořický as Ankerit  $\alpha$ . The analysis of the Admont specimen is given in column  $\alpha$ ; and had I made but one analysis of the Lilleshall mineral, I should perhaps have felt justified in calling it ankerite. Analysis 2, however, was made from a specimen undistinguishable in appearance from specimen 1, yet the relative proportions of carbonates are widely different. Analysis 2 cannot be made to coincide with either of Bořický's values for ankerite\*. The specimen, however, approximates to the formula



which requires  $\text{CaCO}_3$  60.00 per cent.,  $\text{FeCO}_3$  23.20 per cent., and  $\text{MgCO}_3$  16.80 per cent., or a difference of 1.34 per cent. in the  $\text{CaCO}_3$ , 0.32 per cent. in the  $(\text{FeMn}) \text{CO}_3$  and 0.76 per cent. in the  $\text{MgCO}_3$ , and would properly be described as a ferriferous dolomite.

\* Bořický (Mineralogische Mittheilungen von Tschermak, 1876, Heft i. p. 47) gives the general formula for ankerite as



where  $x = \frac{1}{2}, 1, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}, 2, 3, 4, 5, 10$ ; so that the possible ratios of carbonates are

$$\begin{aligned} \text{CaCO}_3 &= 100(x+1), \\ \text{FeCO}_3 &= 116, \\ \text{MgCO}_3 &= 84x. \end{aligned}$$

Putting  $x$  as  $\frac{1}{2}, 1, \frac{4}{3}, \&c.$ , and calculating percentages, we have the following possible values

	$\text{CaCO}_3$ .	$\text{FeCO}_3$ .	$\text{MgCO}_3$ .
$x = \frac{1}{2}$	48.70	37.66	13.63
$x = 1$	50.00	29.00	21.00
$x = \frac{4}{3}$	50.54	25.16	24.30
$x = \frac{3}{2}$	50.81	23.57	25.62
$x = \frac{5}{3}$	51.05	22.18	26.77
$x = 2$	51.37	19.87	28.77
$x = 3$	52.09	15.10	32.81
$x = 4$	52.52	12.18	35.30
$x = 5$	52.81	10.21	36.97
$x = 10$	53.50	5.64	40.85

## DISCUSSION.

Mr. HUDLESTON remarked that since iron and magnesia were freely interchangeable elements, it seemed hardly necessary to base mineralogical distinctions on variations in their respective amounts.

The AUTHOR accepted the views expressed by Mr. Hudleston.

26. *On a SECTION recently exposed in BARON HILL PARK, near BEAUMARIS.* By T. G. BONNEY, M.A., F.R.S., Sec. G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read May 23, 1883.)

IN the autumn of 1880 I observed by the roadside leading up the hill from the gates of the Beaumaris Cemetery towards Llandegfan some peculiar grits which reminded me much of certain beds exposed in the district near Perfeddgoed House and other places in the neighbourhood of Bangor. The rock, which crops out here and there by the roadside (perhaps about one third of a mile from the road to Menai Bridge) varies from a green "bastard" slate to a grit containing small grains of reddish felsite. These beds are succeeded, after a very short interval, by the normal greenish micaceous or chloritic schists of the region. Although convinced that this indicated an extension of the group of beds which in the Bangor area underlie the conglomerate now generally taken as the base of the Cambrian, such specimens as I could obtain might not have convinced others, and I waited for a more favourable opportunity of examining the district. Last summer, while on a visit to some friends in the neighbourhood, I was informed by them that a new drive was in process of construction through the woods on the face of the hill mentioned above; and I applied, as the grounds of the Baron Hill estate are strictly private, to the owner, Sir R. Williams Bulkeley, for permission to examine the sections. This was at once accorded to me most courteously, and the results proved even more interesting than I had anticipated.

The new drive is carried along the face of the craggy scarp which overlooks the Menai Straits, and is obviously an old line of cliffs, the base, as we approach Beaumaris, being now separated from the water by a considerable tract of nearly level ground. The drive ascends gradually along the face of the scarp, and crosses by means of a bridge the lane already mentioned close to the outcrop of the aforesaid grits.

On entering the grounds from the main road, some little distance north-east of the Ferry from Garth, we find greenish and purplish schists, overlain by a compact chloritic schist, which dip at a rather low angle, roughly S.E. Then come other greenish and purplish schists with thinner bands of the more compact rock, followed, yet higher, by a fissile green micaceous schist. This is succeeded by a compact purple variety, traversed by quartz-veins and looking as if silicified. So compact is it in structure that it might readily be mistaken for a flinty argillite.

These schists may also be seen, though in a condition less favourable for examination, cropping out by the roadside below, and the last named is identical with a rock exposed in a knoll by the turn-pike, which had always been a great puzzle to me. The dip here-



abouts appears to be about E., or even a little N. of E., but it bends back again to the S.E. The last schist exposed is of a greenish colour and rather compact structure, with some epidote and quartz-veins, which dips roughly  $20^{\circ}$  E.S.E.\* Here we are on the higher ground, a little west of Gallows Point, overlooking the strip of flat land already mentioned. These schists are cut by two or three basalt dykes †.

I have had slides cut from the principal varieties of the schist for microscopic examination. The purplish schist (about 150 yards from the entrance to the drive) consists of quartz, a flaky green mineral, and an iron-oxide (probably hæmatite) associated with a little manganese. The quartz is in irregular granules of chalcedonic aspect, I believe developed *in situ*. The other two minerals are to some extent scattered over the slide, but are also associated in wavy bands. In part the former may be a chlorite; but I am disposed to regard most of it as a hydrous mica akin to biotite. I have examined these minerals with considerable care, but cannot say that I feel much confidence in determinations of the optical characters of these small crystallites, as there are so many obvious sources of error. In the compact chloritic rock, near the entrance-gate, there is more of the green mineral, some of which more closely resembles a chlorite, and less quartz and ferrite; calcite also occurs in a vein. The highest schist exposed in the drive has a general resemblance to the first

\* An interesting section is exposed in a pit near a house called, I believe, Pen-y-Parc, a short mile from the cemetery-gate. Here is a compact greenish-white quartzite overlain by a dull greenish-grey schist. The upper surface of the former is rather uneven; but I incline to consider this the result of a bending of the beds, and not to indicate an unconformity. The former consists of quartz-grains of variable size, subangular to rounded, the larger being the most rounded, imbedded in a minutely granular quartzose matrix, the whole being occasionally cracked and recemented by very minutely crystalline quartz, in which are occasional flakes of a pale greenish micaceous mineral. The quartz-grains are generally crowded with small cavities, in very many of which are minute moving bubbles, occasional small prisms of a pale green mineral, and fine "hairs" like rutile. The schist is less altered than one would expect; it consists of small subangular grains of quartz in a matrix of quartz and the usual filmy green mineral, with an occasional larger flake of pale mica. The whole has evidently been much compressed. Some twenty feet or so of the quartzite are exposed, and a little lower down the hill schists resembling those already described crop out. Macroscopically one would correlate these beds with the other schists; but the dip, which is about N.N.E., does not agree very well, the quartzite is not seen on the scarp below, and the retention of a fragmental condition, probably original, in the upper schist is a good reason for hesitating. The quartzite has a considerable resemblance to that on Holyhead Mountain, though in the latter bubbles seem to be much less frequent. Both, however, may very well have obtained their materials from such rocks as the granitoid series near Ty Croes.

† The last seen of these consists of a plagioclasic felspar well preserved, with rather large angles (up to  $30^{\circ}$ ) between the extinctions of successive lamellæ. In these are many colourless belonites. The augite has lost its characteristic aspect, consisting of a mass of granules partly dusky, partly bright-coloured with crossing nicols; there are many scattered rods and well-defined sharply angular crystals of hæmatite or perhaps, in some cases, ilmenite. The minerals appear to have consolidated in the inverse order to that in which they are described.

described, but has less ferrite and a greater proportion of the micaeous constituent in rather large folia. The compact purple rock, resembling a flinty argillite, shows a clear matrix, studded with belonitic crystallites of a pale yellowish-green colour and with innumerable granules of the above-mentioned ferruginous constituent, arranged in wavy parallel bands. The matrix is siliceous, partly chalcedonic quartz and partly, I think, opal. Though the constituents are very minute, the rock appears to be rightly considered a true schist; and I suspect its abnormal aspect is partly due to a subsequent infiltration of silica. I have compared these slides with specimens from near Menai Bridge, which much resemble the first and third (except that they have a hydrous white mica), and several specimens from the north-west of Anglesey, including those described in my Appendix to Dr. Callaway's paper (*Quart. Journ. Geol. Soc.* vol. xxxvii. p. 234, Group B). All these have a strong general resemblance one to another.

Beyond the last-named schist is an interval of about 60 yards, where every thing is concealed beneath loose soil and vegetation; and then comes an outcrop of a massive grit, hard, jointed, weathering to a brownish colour, and at the first glance rather like one of the intrusive masses of basalt further down the hill. It is at first fine in texture and dark in colour; then it becomes a little coarser, and is full of rolled grains, up to about the size of a small pea, of felspar and felsite, which weather white. More angular fragments of a very compact black rock, up to nearly 2 inches in diameter, now and then occur. These grits are exposed by the roadside for about forty yards; their dip is not easily ascertained, seemingly it is to the east. There is then an interval of 18 yards covered by vegetation, followed by an exposure of a similar grit for about 16 yards. Another interval of 60 yards succeeds, and we then find a slightly finer grit, which passes into hard blackish and brownish argillite, traversed by small quartz-veins, and looking rather crushed. The dip here appears to be about  $25^{\circ}$  E. Grits and argillite alternate for about 100 yards; and then, after another interval of about 36 yards, we find a hard argillite, in the middle of which is a greenish grit dipping towards the E. and exposed for about 130 yards.

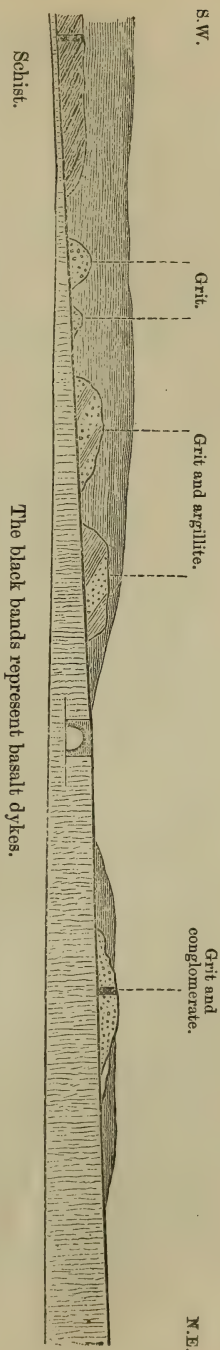
Rather more than a hundred yards from the last exposure of the above-described rock, the lane already mentioned is crossed by a bridge; and in the park on the other side we find a considerable area of rounded surfaces of rock, seemingly ice-worn, partly masked by earth. The first reached is a grit (generally similar to the one last seen on the other side of the bridge), banded with greenish and greyish argillite; this soon becomes coarser, and in it may be noted fragments of the black rock already described, of a green argillite, and pebbles of the purplish felsite so well known on the other side of the Straits. The dips here appear to be high, and to have changed their direction to the N.W.; but in deposits of this nature it is not easy to be sure. Then succeeds, sometimes by a very abrupt transition, a coarse purplish grit or conglomerate (the fragments weathering nearly white), full of bits of the felsite.

In one spot I noted a lenticular patch where the materials sud-

denly became extremely coarse, the felsite fragments being some 9 inches in diameter; the general appearance suggests that this may be an agglomerate rather than a conglomerate. There is also a dyke of a compact dark rock with scattered crystals of whitish felspar often about half an inch long, resembling very closely a dyke in a quarry above the Bangor Cemetery\*. Beyond this spot, for some distance the drive crosses an open field, and the slope is overgrown with vegetation of long standing; so, as there was no probability of any more exposures that would be of interest, I did not follow it further. On the crest of the ridge, about 150 yards to the N.W. or W. of the above rocks, is schist of the ordinary type.

I have examined five slides cut to illustrate this series of grits:—one, from the mass nearest the schists, to represent the normal rock of this part; another, from near the same, to examine more especially the included fragments; a third from the greenish grit associated with argillite, near the bridge on the western side; and a fourth to illustrate the red felsite grit east of the bridge, cut from a part where the fragments are often about the size of small peas. We find, in these, grains of quartz, felspar, and several varieties of tra-

\* I have not examined this microscopically, as I could not have got a specimen worth cutting without much defacement of the ice-worn surfaces. The "Cemetery" dyke has in its ground-mass a considerable family likeness to the one already described, but is a little coarser, and the augite is better preserved. The larger felspar crystals appear to be of the same species as those in the ground-mass, but are more decomposed, and partly replaced by secondary microliths.



*Sketch Section illustrating the General Succession of the Beds exposed by the new Drive in Baron Hill Park.*  
(The vertical height of the outcrops is much exaggerated. Scale about 200 yards to 1 inch.)



chytic lava and lapilli, associated with finer materials, granules of iron-oxide and some viridite, most of this matrix being doubtless decomposed volcanic dust or felspathic mud. The quartzes vary from subangular to rather rounded, the smaller grains generally being the more angular. With a low power they appear rather clear; but with a  $\frac{1}{8}$ -inch objective a considerable number of cavities are detected, generally very small and often associated, mostly containing very minute bubbles, which usually move freely. In a grain in the fourth of the above-named specimens the fluid appears to be stained a reddish-brown colour. The felspar is usually a little more rounded externally. It is rather decomposed, but I recognize in some cases orthoclase, and think this predominates, as I obtain but rarely indications of the characteristic twinning of plagioclase. Of the fragments of igneous rock there are several varieties, even in the same slide. Some are slaggy, and in great part completely opaque with opacite; others are crowded with elongated crystallites of felspar, exactly as in slides from modern trachytic lavas in my collection; others show a cryptocrystalline structure; others, brown-banded with ferrite, show a fluidal structure; some are microporphyritic, exhibiting grains of quartz or crystals of felspar. One fragment in the first-named slide, with a rather irregular rounded exterior bordered with black, appears to be "micro-amygdaloidal," the numerous little vesicles being filled near the exterior with opacite, and within with celadonite (or a green serpentinous mineral) and a clear mineral, probably a zeolite. The whole appear to me to indicate the presence of materials truly volcanic—lapilli and fragments of trachytic lava. Some, at least, of the materials are water-worn; and I should suspect that, as a whole, they have been transported to their present position (though the cones from which they must have been derived were probably at no great distance), rather than have been showered down as they now lie from a volcanic orifice.

The fragments mentioned above, in the second slide, were two, an inch or so in diameter, which lay almost in contact in the first-named grit. Both were a very compact dark rock, but one had weathered to a paler colour. The latter is a rhyolite, with scattered angular grains of quartz and felspar in a matrix crowded with minute granules of ferrite and (apparently) with extremely minute crystallites. There seem to be traces of a glassy base, but this is uncertain. Not so, however, in the other fragment; this exhibits admirably a fluidal structure, wavy bands, almost opaque with granular ferrite, appearing in a clearer base. As the field, except for some scattered crystallites, remains dark with crossed nicols during a rotation of the stage, and does not sensibly vary its tint when a quartz plate is inserted, I consider that we have here a fragment which has retained its original glassy condition.

I have compared these slides with a rather numerous collection from the district near Bangor which I described in a former paper\*. The resemblance to some of these is very close. The fine grit macroscopically most resembles that from a pit near Hendrewen; but

\* Quart. Journ. Geol. Soc. vol. xxxv. p. 309.



microscopically the similarity is less marked. These Anglesey specimens correspond most nearly with the slides obtained from various parts of the series which extends from the coarse breccia at Tairffynnon Quarry up to near the horizon of the Cae Seri rock.

The argillite associated with these grits does not resemble any of the specimens which I have examined on the other side of the Straits; but there I chiefly directed my attention to the coarser beds as more important for classificatory purposes, so that I lay no stress on this difference. Under the microscope it appears, at first glance, not unlike a volcanic glass, consisting of a fairly clear material irregularly tinged with extremely minute granules of ferrite with a slightly wavy banding. In this are scattered rather angular crystalline particles and some patches of a dusky granular mineral. With crossed nicols the ground-mass remains black, except for the presence of many minute crystallites of variable form and often fragmental aspect. The exact nature of these I cannot determine: some look like quartz, others may be feldspar or more probably a zeolitic mineral; the larger patches are granular in structure, in some cases concretionary, in others resembling pseudomorphs after a crystal of feldspar. With ordinary light they are a pale dull grey, like the colour of very diluted ink; with polarized light they prove to be very dichroic, becoming almost black in one position; with crossed nicols they change from a sort of buff tint to black; and on selecting one of the most definite forms, I find that extinction takes place when its longer axis makes an angle of  $45^\circ$  with the vibration-plane of the nicols. I am unable to identify this mineral.

The same mineral occurs occasionally in some of the volcanic fragments in the other slides. I should regard a volcanic mud as the most probable material of this rock. It does not at all resemble the ordinary argillites or porcellanites, and, if a little more altered, would, I think, be a very typical h  lleflinta, *i. e.* a rock of sedimentary origin by no means easy to distinguish from a compact felsite.

The relations of these two groups of rocks are, I think, of importance in reference to some matters of rather recent controversy. Their junction is most probably a faulted one, and no one accustomed to the study of rocks can doubt that the felsitic-grit series is much newer than the schists. The former rocks are but little metamorphosed; the alteration in them is not greater than we find in such beds as those at or just below the base of the Cambrian in Caernarvonshire or Pembrokeshire, at Charnwood, or at the Wrekin; the latter have undergone very considerable metamorphism. As a rule, no original constituent in them can be identified with certainty. I have examined several specimens from this great series of schists, which extends from the west of the Menai Bridge to the neighbourhood of Beaumaris, and only in the case of the quartzite and schist of Pen-y-Parc have I detected original constituents. Once, doubtless, mudstones of variable chemical composition, they are now true foliated rocks, their chemical constituents having entered into new mineral combinations. Changes of this kind may doubtless sometimes occur under exceptional circumstances in a series generally

unaltered, as when the temperature of one part has been locally elevated by the proximity of large masses of igneous rock, or when it has been exposed to very exceptional pressure in the presence of water at a slightly higher temperature than usual; but here there is no reason for suspecting any agent of change to have been more intense than usual. Further, at Garth Ferry we have Ordovician rocks \* quite unaltered; and on the Anglesey shore, on either side of the landing-place, is a quartz grit, faulted down against the schists, entangled with which may be seen some remnants of a slaty rock similar to that on the mainland. This appears to me to be rightly mapped by the Survey as Ordovician, and I should correlate it with the quartz grit and conglomerate near the opening of the sewer at Garth, which, as it seems to me, occurs there in association with the dark slaty beds, and not with any part of the Cambrian conglomerate.

As, then, in the immediate neighbourhood, we find Ordovician rocks and even strata probably rather below the Cambrian practically unaltered, we cannot hesitate to consider these Menai schists Archæan, and should not be disposed to refer them to the newest period in this great group. But these Menai schists have a general resemblance to the bedded schists which abound on Holyhead Island (as already described by myself and others) and in the intervening districts of Anglesey. I think no petrologist could hesitate, in the absence of any evidence of special local metamorphism, to refer all the above roughly to one group. It would therefore seem vain to speculate on any "gnarled rocks," identical in constitution with these, being by any possibility of Ordovician or even of Cambrian age. It might perhaps happen that a small patch of one of the older Palæozoics, locally nipped and tremendously squeezed, should exhibit a "universally slickensided" appearance, which would cause some macroscopic similarity to these true schists; but I doubt whether, even then, there would be much real correspondence when they were examined microscopically. Here, at Baron Hill, we have almost side by side true schists and rock which all must admit to be at least older than the greater part of the Cambrian; yet, as we have seen, the latter is almost unaltered.

We may, then, I think, safely regard these micaceous and chloritic schists of Anglesey as Archæan. By some authors they have been claimed as Pebedian. Here, however, the question arises, What is Pebedian? If we take as its type the series on which the name was first conferred, the group beneath the Cambrian conglomerate at St. David's, we may at once repudiate the identification †. That, like the rocks of Charnwood Forest, is a group largely consisting of volcanic materials and comparatively slightly altered. To such a group we may assign the series in Caernarvonshire between the Cambrian conglomerate and the great rhyolitic masses (which, indeed, I

\* Probably of about Llandeilo age (see Mem. Geol. Survey, vol. iii. ch. xxii.).

† This paper was written prior to the reading of Dr. A. Geikie's paper "On the supposed Pre-Cambrian Rocks of St. David's;" but, notwithstanding the efforts of the Director General to efface the limit between Cambrian and Pebedian, the author sees no reason to alter any thing that he has written here.

should include with the overlying beds). With some part of this the felsitic grits at Baron Hill probably correspond.

The term Pebidian, then, should designate a comparatively unaltered series (hypometamorphic, as it has been called by Dr. Callaway) which does not appear to be much more sharply marked off from the Cambrian than the Ordovician from the Silurian. It is especially characterized by an abundance of volcanic material, chiefly of an acid type. So far as we can conjecture, it appears to have commenced (I speak, of course, only of Britain) by an epoch of volcanic activity, when, from orifices opened probably on an old land surface of the more ancient Archæan rocks, flows of glassy lava and great masses of trachytic scoria were discharged—and to have been followed by gradual subsidence, which probably became still more general in the Cambrian period.

[*Note*, June 26, 1883.—Since this paper was written I have received, through the kindness of Dr. J. W. Dawson, F.R.S., a very interesting series of small specimens of Huronian rocks from Canada. I have not yet had time to examine the microscopic structure of these; but macroscopically the resemblance of not a few of them to certain of the Pebidians of St. David's and some of the rocks from Charnwood is most remarkable. They are, however, wholly different from the true schists described in the above paper.]

These Anglesey schists (which present considerable resemblance to certain rocks recently described by myself from the Lizard district, and could perhaps be paralleled by others from the older part of the Pietra Verde group of the Alps) must be regarded as distinctly older than the typical Pebidian. The correlation of them with the last-named group was due, I think, to two misconceptions—an erroneous identification of an Arvonian series in this part of North Wales, and an overestimate of the amount of metamorphism in the St. David's Pebidians. As regards this correlation I see no escape from the following dilemma. If there is Arvonian at Ty Croes (Anglesey), then the schists of Holyhead Island and the Menai must either be much older than the Pebidian or the term must cease to have any classificatory value, as it would include rocks so very dissimilar in their amount of metamorphism.

In the above remarks I have not attempted to correlate precisely the Baron-Hill grit with the beds on the mainland. All that I maintain is, that it cannot be newer than the Cambrian Conglomerate of Professor Hughes or older than the great flows of rhyolite. Any thing more than this would involve a digression into the stratigraphy of the beds near Bangor, which I reserve for a separate paper. I may, however, observe that the Baron-Hill beds differ considerably both from the conglomerate which, for some distance, fringes the opposite side of the Menai Strait and runs inland to the east entrance of the tunnel west of Bangor Station, and from that on the top of the hill above the eastern tunnel, both of which are referred by Professor Hughes to the base of the Cambrian series.

(*For the Discussion on this paper, see p. 485.*)



27. *On the Rocks between the QUARTZ-FELSITE and the CAMBRIAN SERIES in the Neighbourhood of BANGOR.* By T. G. BONNEY, M.A., F.R.S., Sec. G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read May 23, 1883.)

THIS district has already been the subject of papers published in the Quarterly Journal of the Society \*. The authors of these agree in accepting the coarse conglomerate exposed (for instance) on the upper part of the hill pierced by the eastern tunnel of the railway near Bangor, as the base of the Cambrian; but there is still some diversity of opinion as to the relations and extent of the subjacent series. The views on the latter point will be found respectively expressed in papers by myself and Professor Hughes in vol. xxxv.; and since the publication of the latter I have four times revisited the district, leaving, I believe, but few exposures of the rock unexamined (except such as may occur unknown to me in private grounds). As I adhere to my original opinion as to the sequence of the beds, I now ask leave to state as briefly as possible the additional evidence which I have succeeded in gathering. At the same time I am glad to take this opportunity of frankly admitting that in the part of his paper which treated of the relations of the conglomerate and the granitoid rock at Twt Hill I was wrong, and Prof. Hughes was substantially right. Repeated examination of the district and of specimens under the microscope has convinced me that, notwithstanding the apparent passage of the one into the other, the conglomerate is much later in date than the granitoid series. Whether it be of the same date as the Cambrian conglomerate in the Bangor area is, I think, at present by no means certain. I can hardly regret the mistake, for in the correction of it (as related in Geological Magazine, decade 2, vol. ix. p. 18) I have learned much; and that I made it at all was, I believe, due to the last lingering impressions of the instruction which I had found in the writings of those whose teaching was regarded some dozen years ago as authoritative. Had I then commenced my petrological studies in a spirit of absolute scepticism, I should have been saved much time and some errors.

The main point, however, at issue between myself and Professor Hughes with regard to the Bangor district is the following:—I had described in the district south of the fault, which runs nearly along the line of the road from Bangor to Caernarvon, a series of rocks in which occurred at least four well-marked beds of breccia or conglomerate, which appeared to me to be so distinct that I could only conclude that they indicated horizons, and that the succession as a whole was an ascending one. Three of these, unless I misunder-

\* Vol. xxxiv. pp. 137 & 147, and vol. xxxv. pp. 309 & 682.



stand him—all, in short, but the greenish breccia which occurs on Bangor mountain, Professor Hughes considers to be only the Cambrian conglomerate repeated by faulting, so that the series separating the quartz felsites from the conglomerate at the base of the Cambrian is reduced to the above-named green breccias and the gritty slates in association with them—that is to say, rather less than one half of the thickness which I should assign to it. Of the faults which are needed for this repetition I have not been able to find satisfactory evidence in the field. The principal argument for their existence appears to be the hypothesis that one conglomerate is equivalent to another, an argument which it is obvious stands or falls with the hypothesis.

I commence, then, my revision of the district with the eastern edge of the great mass of quartz felsite near Brithdir Farm. In apparent succession to this (I could not discover any evidence for the intermediate band of slate inserted on Prof. Hughes's map) we find (on both sides of the lane which mounts in a S.S.W. direction from the main road along the bed of the valley) a grit mainly (if not wholly) composed of quartz, felspar, and felsite fragments, occasionally becoming conglomeratic and containing pebbles of felsite, which can be traced pretty continuously round the brow of the hill near Wern, until, on its northern scarp, we again come to the main mass of felsite. We pick it up by the high road in the valley below (on the other side of the fault), still in apparent sequence with the felsite; we follow it by Taffarn newydd to Beulah Chapel, where it is still in sequence, and find it thus in the field-way leading to a farm opposite to the lodge of Gorphwysfa, and it is seen for the last time just above the west entrance of the western tunnel. This felsite grit, the constituents of which certainly seem to have been derived mainly, if not wholly, from the adjacent felsite, appears to be succeeded near the turning to Wern Farm by greenish grits and a little purplish slate, over which comes a rock rather like that at Tairffynnon quarry, varying from a green grit with reddish spots to a coarsish breccia or conglomerate more like that in the above quarry. It is also worth notice that about 80 yards to the east of the above-named tunnel-entrance is a small outcrop of a similar rock, and many fragments are to be seen in a spoil-bank consisting of materials which have doubtless been obtained in making the tunnel.

It seems, then, not unreasonable to suppose that this grit and conglomerate, which, for purposes of reference, I will call A, thus seen at intervals between two points about  $1\frac{3}{4}$  mile apart in a straight line, is in true sequence with the felsite, and is not brought by a fault into its present position.

The next breccia which I have described (we will call it B) is well exposed in a pit in the wood at Tairffynnon, and some overlying beds of a more slaty character are seen in the lane. As mentioned in my paper in the 'Geological Magazine,' I have since traced it on the upper parts of the ridge to the N.N.W. (roughly) of that pit; and in 1880 I found that a new pit opened by the Caernarvon road

had exposed a similar rock almost exactly at the spot where I had anticipated it would occur. At this place the dip appears to be rather to the N. of E., perhaps E.N.E., while the dips about Tairffynnon are generally about E.S.E., a twist towards the northward of which we have other indications near this fault. This breccia, then, retaining its characteristic aspect, has now been traced for above half a mile.

The peculiar breccia (C), containing elongated fragments of purple slate with smaller bits of felsite, had been traced prior to 1880 from near Tyddn Dreiniog to Cae Seri; and I had stated that I expected it would occur in the neighbourhood of the Poorhouse. In that year I observed a pit (perhaps 200 yards to the south-east of the building, which had been overlooked at my former visit) in which I found a rock impossible to distinguish from the Cae-Seri rock. Here also the dip (difficult to ascertain) seemed to be about N.E., a direction which is confirmed by other observations in greenish grits and slates in the neighbourhood.

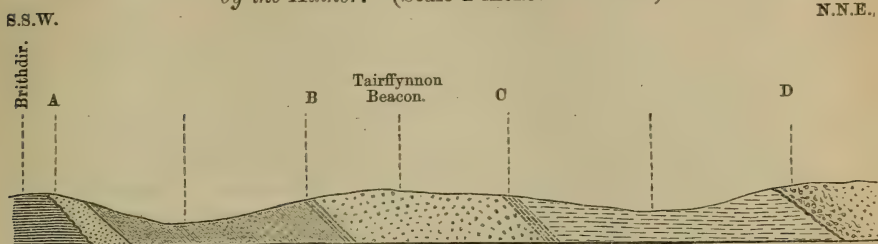
During a brief visit in 1882 I found traces of a similar rock in the interval between this pit and Cae Seri. This peculiar breccia (C) has now been traced for a distance of full a mile as the crow flies.

In succession to this comes, I believe, the greenish-grey felsitic grit of the Hendrewen quarry, in which are occasional well-rolled pebbles of similar-coloured felsite. Under the microscope it is seen to consist of fragments (generally rounded) of quartz, felspar, and an acid lava. The last commonly show more or less of a fluidal structure, and, examined with polarized light, are cryptocrystalline; but two or three are crowded with elongated crystallites of felspar, as may be seen in many trachytes. The materials are rather more decomposed than is usual in the other breccias. There is also one rounded fragment of a quartz grit. The grit described from the quarry by the white cottages west of Minffordd (I think the spot called Nant Gwtherin on the map) has some resemblance to this from Hendrewen, and is probably higher up in the same series.

So far as I can gather from Professor Hughes's map and paper (vol. xxxv. p. 682), he regards the quarries at Hendrewen and at the back of the Poorhouse as both in Cambrian conglomerate (pp. 690, 692), but the one near Nant Gwtherin and the rock of Cae Seri as part of the Bangor beds.

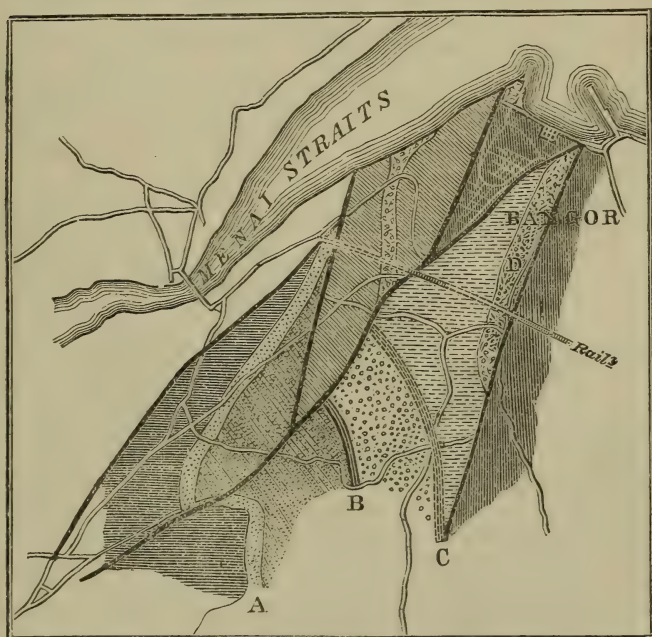
The district between B and C is one not easy to unravel. I have zigzagged over it, and found most of the outcrops to be greenish gritty rocks, sometimes pink-spotted; and near Brynllwyd Farm are conglomerates, one of which contains some fragments of purple slate like that in the Cae-Seri breccia. At this place (*e.g.* near Careg Hwfa) Professor Hughes again brings in the Cambrian conglomerate. I cannot, however, say that the rock closely resembles any of the admitted exposures of the latter, though it has something in common with both B and C. Hence I think it more natural to regard these conglomeratic beds as merely local intercalations in the intervening zone.

Fig. 1.—Sketch Section to illustrate the General Succession of the Beds as maintained by the Author. (Scale 2 inches to 1 mile.)



For explanation, see Map, fig. 2.

Fig. 2.—Sketch Map of Bangor district, founded on the Geological Survey Map, from which the Faults (except the hypothetical one N.W. of the Cuernarvon Road) are taken. (Scale 1 inch to 1 mile.)



- |                            |                          |
|----------------------------|--------------------------|
| Ordovician.                | Grits.                   |
| Cambrian ?                 | Tairffynnon Breccia (B). |
| Cambrian conglomerate (D). | Slates and pink grit.    |
| Bangor series.             | Felsite Grit (A).        |
| Cae-Seri Breccia (C).      | Felsite.                 |

The black lines indicate faults.



The Cambrian conglomerate (D), above the admitted Bangor Series on the hill pierced by the tunnel east of the station, is as different as it well can be from B and C, but somewhat resembles A; from which, however, it differs in containing numerous pebbles of quartz and quartzite (exceeding in number those of felsite), and in possessing a more sandy matrix.

If, then, A, B, C, and D are the same rock, we must suppose:—

(1) That whenever there is an exposure along the edge of the quartz felsite for more than  $1\frac{3}{4}$  mile, either the whole Bangor series is overlapped by the Cambrian conglomerate, or the latter by faulting is exactly fitted onto the igneous rock, and is composed of materials wholly, or almost wholly, derived from it.

(2) That in the space of about  $1\frac{3}{4}$  mile, measured at an angle of about  $45^\circ$  with the general strike, the Cambrian conglomerate changes from a rock consisting almost wholly of felsite to the mixed but different and more brecciated types of B and C, and then returns to the more similar bed D, with its well-rolled pebbles.

The annexed section (fig. 1) represents diagrammatically the result of the observations described in the above remarks; and when we regard the general agreement in dips and the lithological character of the rocks, it seems more natural to consider the whole an ascending series, and to extend the Bangor beds of Professor Hughes down to the quartz felsites. On the map (fig. 2) I have endeavoured to record the same observations as well as can be done on one of so small a scale.

As regards the district between the Menai Strait and the fault running S.W. from Bangor down the valley, which has frequently been mentioned above, I have little to add, notwithstanding repeated examination, to what I have incorporated in the foregoing remarks. Above the conglomeratic grits therein mentioned, and the great conglomerate extending from the shore by Gored Gith to the eastern entrance of the west tunnel, we find nothing but greenish or purplish slaty beds, occasionally slightly gritty, which perhaps generally agree better lithologically with the normal Cambrian than with these underlying beds; but the prevalent dip appears to carry them under the conglomerate. This same conglomerate, so well exposed for a considerable distance, as traced by Professor Hughes (over half a mile), is a little perplexing. Felsite forms a much larger proportion of its materials than is the case in the conglomerate pierced by the eastern tunnel; and it seems intermediate between this and the one near Gorphwysfa\*. Still, as it retains its character so uniformly for so great a distance, and terminates within less than half a mile of the Poorhouse quarry, we can hardly, I think, regard it as on the same horizon as the breccia (C), or, what would be simpler, identify it with that in the Hen-

\* This resemblance, and the occurrence of a patch of conglomerate between the two, caused the perplexity about the position of that near Gorphwysfa, mentioned in *Geol. Mag.* decade 2, vol. vii. p. 302, which was not removed till 1880.



drewen pit \*. It does not, however, appear to me that the quartz and jasper grit and conglomerate west of the pier at Garth can be associated with the above. The following extract from my notebook explains the sequence of the rocks on this part of the shore:—“W. of the new slate-pier are dark beds, resembling in the upper part those on the other side of the pier mapped as Arenig, and in the lower becoming gritty and containing bands of small pebbles only a few inches thick, the general dip being  $10^{\circ}$ – $20^{\circ}$  S.E. Then we come to green and purple bastard slates, faulted down, and in places much disturbed in consequence, the prevalent dip (not easy to ascertain) being apparently  $40^{\circ}$  S.W. Just west of the old slate-pier is a bank of scree of bastard slate and fine grit, among which I found bits of green breccia, reminding me of those seen above Bryniau, though in a much finer condition. About 150 yards east of the bathing-place green-banded argillites dip at about  $40^{\circ}$  S.E., and slaty beds then continue to the bathing-house, when the conglomerate sets in, which, so far as one can ascertain, has an easterly dip.” If these observations are correct, it is evident the whole district is completely smashed up by faults.

I have, however, found a rock, seemingly just on the north side of the main fault in the Caernarvon-road valley (in a quarry north of the crossing of the road from Maesmawr to Brithdir), bearing some resemblance macroscopically and microscopically to that at Tairffynnon; and in a pit at the back of Caemabadden Farm is a greenish grit, which, in its coarser parts, contains bits of green slate and red felsite, and may belong to the upper part of the zone between B and C. If I am correct in the position I assign to the bed A, then the whole series north of the fault has a strike rather to the east of N.N.E.; so that all the upper part of the Bangor series would be cut out by the faults which bring down the very Cambrian-looking beds above the cross roads at Pen-y-chwintain.

Until the outcrops can be laid down on a map on the 6-inch scale, it will be hopeless to come to any satisfactory conclusion in this complicated district north of the fault, and not easy to bring into complete order that on the southern side. I trust, however, that I have succeeded in showing that my original reading is the more simple explanation of the facts observed both in the field and with the microscope—namely, that there is a general ascending succession in this district, and that under the name of the Bangor Beds we must include not only the green gritty slates and breccias assigned to them by Professor Hughes, but also a large lower group extending from A to a little above C. This group has probably derived much of its material from the denudation of the great masses of rhyolitic lava to the south-west, and the lapilli which are often present may have been derived from its associated cones. At the same time, seeing that these lavas appear generally to rest upon old gneissic and granitoid rock, the slaty fragments, often very

\* Which would be lithologically the least difficult, were not this grit apparently so completely “sandwiched” between the Bangor grits and breccias and the Cae-Seri breccia.

angular, would not seldom be more simply explained by supposing that sporadic volcanic action still continued, and that indurated fragments of the finer sediments formed from the denudation of the somewhat older lavas and ash were ejected together with lapilli.

I see no reason for insisting on any great interval of time between the rhyolitic lavas and the base of the Bangor beds. An unconformity there seems to be; but that in a volcanic series is of little moment; and I am of opinion that on the whole it would be better to include these quartz porphyries or quartz felsites (old rhyolitic lavas) with the Bangor group. This belongs to the disturbed episode anterior to the quiet subsidence which marks the non-volcanic sedimentary series everywhere recognized as Cambrian. From the latter we seem justified lithologically and physically in separating these more or less volcanic beds, and in including them for convenience in the Peibidian group of Dr. Hicks; but the interval in time need not have been a very enormous one. Below the rhyolites, as it seems to me, is the great gap in the record. They apparently broke forth, as the older basalts in Auvergne, upon a plateau of crystalline rocks which belong to some of the earlier, as these do to the last, chapters in the Archæan volume of the Geological History.

*Note.*—As I believe that no analysis has been published of any specimen from the great masses of quartz-felsite, which occupy so considerable an area in this part of North Wales and contribute so largely to the rocks immediately overlying them, I take this opportunity of giving one, for which I have to thank my friend Mr. J. J. H. Teall, F.G.S. It was made from a very typical specimen of the common purplish variety, collected from the crag near Brithdir Farm (No. I.). For comparison, I place beside it an analysis of the “devitrified pitchstone” of the Wrekin district (No. II.), of a felstone (of Arenig age) from Aran Mowddwy (No. III.), and of a felsite of Bala age from the Lledr valley (No. IV.). The last, an analysis of a specimen of the ground-mass of the peculiar spherulitic rock described on p. 290 of vol. xxxviii. of the Quarterly Journal, was kindly undertaken for me by Mr. F. H. Hatch of University College, London, when I was engaged on my paper “On some Nodular Felsites in the Bala Group of North Wales;” but the result, owing to an accidental delay, did not reach me in time for publication.

The close correspondence between I. and II. is most remarkable. The Ordovician felsites (III. and IV.) agree fairly together, and differ from the other pair in a larger percentage of  $\text{SiO}_2$ , a less percentage of alumina and alkalis, and in an excess of  $\text{Na}_2\text{O}$  over  $\text{K}_2\text{O}$ .

	No. I.	No. II.	No. III.	No. IV.
SO <sub>2</sub> .....	72·57	72·18	83·802	79·72
Al <sub>2</sub> O <sub>3</sub> .....	13·64	14·46	7·686	9·65
Fe <sub>2</sub> O <sub>3</sub> .....	2·28	1·78	·111	5·69
FeO .....	...	·91	·408	...
BaO .....	slight trace	...	...	...
CaO .....	1·00	0·92	·896	†
MgO .....	·64	trace	·109	†
K <sub>2</sub> O .....	6·17	6·10	2·161	1·93
Na <sub>2</sub> O .....	2·07	1·92	4·229	3·54
FeS .....	...	...	·191	...
Loss on ignition ...	1·10	1·47	·301	...
	99·47	99·74	100·000*	100·53

No. I. By J. J. H. Teall, Esq., F.G.S.

No. II. By J. A. Phillips, Esq., F.R.S., Quart. Journ. Geol. Soc. xxxiii. p. 457. Cf. the analyses there given of modern "perlites."

No. III. By J. Hughes, Esq., F.O.S., Quart. Journ. Geol. Soc. xxxi. p. 400.

No. IV. By F. H. Hatch, Esq.

#### DISCUSSION.

Prof. HUGHES remarked on the confusion among the Archæan rocks arising from their classification according to similarity of character, previous to exact determination of their relations to one another in each area. He could not agree with the author in saying that any of the beds east of Brithdir now described were identical with those of Holyhead and Amlwch. He had failed to find any break or unconformity in the British Archæan. He could not agree with the author as to the succession of grits and conglomerates indicated, as he took the strike to be in some cases at right angles to that assumed by the author; so that the author's bands, according to him, were in one part to be referred to the Cambrian conglomerate and in another part of the same band to the Bangor series. Noticing the frequency with which volcanic series, when traced along the strike, pass into ordinary sedimentary rocks, he thought that the relation of the Pebidian to beds not of volcanic origin in adjoining areas might be regarded as still an open question.

Mr. TEALL stated that his analysis had been made quite independently of that of Mr. Phillips.

Dr. HICKS remarked on the discordance of strike of the Pebidian rocks from that of the beds above and below. The granitoid, felsitic, and volcanic groups of Prof. Hughes agreed fairly well with his Dimetian, Arvonian, and Pebidian; but neither of these is fully represented here. Unquestionably the Cambrian conglomerates overlap each group with a marked unconformity, and are mainly made up of fragments derived from the groups below. This unconformity

\* Including ·089 phosphoric acid, ·017 of sulphuric acid, and a trace of carbonic acid.

† Traces, amount not estimated.

occurs in all the areas examined. He believed that the existence of the Arvonian would eventually be fully established. He thought that the author's studies would serve to establish a fourth Archæan series in addition to his own.

Mr. TOPLEY said it was admitted by the author that the unconformity between the Cambrian and underlying beds was comparatively small and local; which was a very different conclusion from that previously announced by Dr. Hicks, who required the Cambrian conglomerate to override some thousands of feet of Pebidian beds within a distance of little more than a mile.

The AUTHOR, in reply to Professor Hughes, said that he thought all the evidence pointed to the Menai and Holyhead schists, with others inland in Anglesey, being approximately of one age. In neighbouring districts and under similar circumstances, he thought lithological correspondence gave a reasonable presumption in favour of a general correspondence in age. In the Bangor district he was fully sensible of the difficulties mentioned by Professor Hughes, especially as regards the conglomerate at Gorphyswfa and the exposures between it and the great mass running up from the shore. Still, on the south-east side of the fault, he thought the succession was clear and the improbabilities of the identity of any of the coarser fragmental beds were too great. He said, in reply to Dr. Hicks, that he did not deny that there might be a series in South Wales representing what the speaker called Arvonian; but in the Caernarvonshire districts he could not find hálleffintas, but there were true acid lavas. With reference to Mr. Topley's remarks, he stated that what he had said was, that he considered there was, under the rocks generally recognized as Cambrian, a series sufficiently distinct stratigraphically and lithologically to justify, in accordance with the usual laws, the giving of a separate name (*i. e.* Pebidian). Whether Dr. Hicks or Prof. Hughes might or might not have overestimated the amount of the break, whether they agreed or disagreed, clearly was for them and not for him to settle. Each man, in the matter of mistakes, if he made them, must bear his own burden, as the author had done by his remarks admitting a mistake of his own at Twt Hill, which had been corrected by Prof. Hughes.



28. NOTES on some FOSSILS, chiefly MOLLUSCA, from the INFERIOR OOLITE. By Rev. G. F. WHIDBORNE, M.A., F.G.S. (Read March 7, 1883.)

## [PLATES XV.-XIX.,]

IN surveying the Inferior Oolite as it appears in the West of England generally, the conditions of deposition seem to differ from those of the Great Oolite as displayed at Minchinhampton, where, in the great frequency of rolled and broken organisms and the extreme false bedding, we have indications of a shore-deposit formed by a roughish sea. The fossils of the Inferior Oolite, on the other hand, are usually better preserved and unbroken; they are often crowded, and lie one inside another, but rarely show great signs of being rolled; so that they do not seem to have been much exposed to actual breakers. At the same time the strata would appear to have been often laid down in shallow water; such shells as oysters, pectens, and astartes are frequent; the univalves are often spinose and nodular; signs of vivid colouring occasionally remain; corals and sponges commonly occur; and the shell-structure of many species is massive, owing to their not being deep-sea forms.

It is interesting to notice the great definitiveness with which beds of different shells succeed each other. For instance in the iron-shot beds of Dundry there is hardly a sign of a *Terebratula* or of the common form *Pholadomya Heraulti*, while in adjacent beds these two fossils occur in crowds; a little higher up corals are common, while the mollusca are, to a great degree, absent. In the same way in Dorsetshire beds appear very full of sponges, though these are very rare in other parts of the formation; nor is it less striking to observe the thick beds of sand which are locally interposed at various horizons. We may therefore believe that the deposits were formed at an irregularly varying level, but in shallow water, and probably not near the entrance of any river.

The absence of the vertebrata is marked; but a *Strophodus* occurs at Broadwindsor, and an *Oxyrhina*? at Dundry. *Acrodon* is quoted by Phillips, in his 'Valley of the Thames,' from near Stroud, and teeth and palates by Wright in the Quart. Journ. Geol. Soc. vol. xvi. p. 40, from Ravensgate Hill. I am not aware of any other species till we come to the rich Sevenhampton and Stonesfield beds, with their vertebrata and even mammals.

The large size of the mollusca, especially Pelecypoda or bivalves, the great number and variety of gigantic Cephalopoda, and the presence of numerous fine species of corals and *Echini* would point to a temperature considerably warmer than at present. On the whole, the fossils would appear to increase in size and variety as we go southwards. This is less seen in the Lamellibranchs and Brachiopoda than in the Cephalopoda and Gasteropoda. These latter are rare in the Cotteswold and Midland districts, common at Dundry, and abun-

dant in Dorsetshire. The large size of the mollusca at Dundry is very noticeable in the field.

In the highest part of the *Humphriesianus*-zone at Dundry very numerous nodules occur of a more or less egg-shaped form. These I at first thought to be sponges; but, upon having them tested and sliced for microscopical examination, Mr. Sollas could find in them no clear remains of structure. They consist of fine marly limestone, have a well-defined rounded surface with one or two deep depressions, and appear generally to have a coral as nucleus. In spite of finding no structure, I cannot help believing them to be of organic origin, either allied to the Nullipores or some such growths as we now so often find about low-water mark. If so, they would indicate still further the depth at which the deposit was formed.

In the following descriptions I have confined myself almost exclusively to the Lamellibranchs. Having been permitted by Prof. Sollas to study those in the Bristol Museum, several species among them seemed to me undescribed; and I was confirmed in this opinion by the fact that the late Mr. Tawney, when he had arranged these shells a few years before, had left them without names. After this I was enabled, by the kindness of Dr. Woodward, Mr. Etheridge, and Mr. E. T. Newton, to examine the shells from the same strata in the British and Jermyn Street Museums, and there found some additions to the list. Other species are from my own collection. To these bivalves I have added one or two other fossils that appeared to me of interest. I am under great obligations to Mr. Etheridge, F.R.S., and other friends for assistance in respect to several of the following species, and to Mr. Foord, F.G.S., for the careful drawings which accompany this paper.

ANCYLOCERAS WALTONI, MORT. Plate XIX. fig. 1.

1845. *Ancyloceras Waltoni*, Morris, Ann. & Mag. Nat. Hist. vol. xv. t. 6. fig. 5.

1845. ? *A. costatus*, Morris, Ann. & Mag. Nat. Hist. vol. xv. t. 6. fig. 4.

1849. *A. subannulatus*, D'Orb. Pal. Fr. Amm. Jur. t. 225. figs. 8, 9.

1881. *A. subannulatus*, Buckman, Q. J. G. S. vol. xxxvii. p. 607.

D'Orbigny gives Morris's two species as synonyms for *A. annulatus* (Desh.); but as his chief reason for separating his *A. subannulatus* from the former shell appears to be the permanence of the ribs on the dorsal side, and as this is very decidedly seen in the form which is common at Burton Bradstock, there seems to be no reason for sinking Morris's name. Whether his two species are not different portions of the same shell would seem more doubtful, both from an examination of specimens and a comparison with D'Orbigny's fine figure of the kindred *A. annulatus*. Morris, in the second edition of his Catalogue (1854), unites the two species; Buckman (*loc. cit.*) in 1881 again separates them.

TOXOCERAS ORBIGNYI, BAUGIER & SAUZÉ. Plate XIX. fig. 2.

1843. *Toxoceras Orbignyi*, Baug. & Sauz. Not. sur quelques Coq. t. 3. fig. 18.

1849. *T. Orbigny*, D'Orb. Pal. Fr. Amm. Jur. t. 231, & t. 232. figs. 1 & 2.

1881. *T. Orbigny*, Buckm. Q. J. G. S. vol. xxxvii. p. 608.

Mr. Buckman records its occurrence in the Inferior Oolite of Half-way House, and the specimen from which the accompanying figure is taken came from the same locality.

*OSTREA CONCENTRICA*, Münst., var. *MUNDA*. Plate XV. fig. 1.

1834.? *Ostrea concentrica*, Münst., Goldf. Petr. Germ. t. 80. fig. 1 (only?).

1836.? *O. lingua*, Röm., Verst. ool. Geb. t. 3. fig. 6 (also figs. 7 & 12).

1837.? *O. multiformis*, Koch & Dunker, Verst. nordd. Ool. t. 5. fig. 11 (part).

1850.? *O. multiformis*, D'Orb. Prodr. pt. 2, p. 54.

1853.? *O. Sowerbyi*, Morr. & Lyc. Gt. Ool. Moll. pt. 2, t. 1. fig. 3.

1861.? *O. multiformis*, Thurm. & Et. Leth. Bruntr. t. 39. fig. 5.

1864.? *O. multiformis*, Seeb. Hann. Jur. p. 94.

1871.? *O. Sowerbyi*, Phill. 'Valley of the Thames,' t. 4. fig. 3.

1871.? *O. Sowerbyi*, Terq. & Jour. Mém. Soc. Géol. France, sér. 2, vol. ix. pp. 133, 134.

? 1871. *O. concentrica*, Terq. & Jour. Mém. Soc. Géol. France, sér. 2, vol. ix. pp. 133, 134.

Shell nearly flat, equilateral, very long and narrow, egg-shaped, but more pointed at umbo, which represents the small end of the egg. Umbo central, acute and distinct, but very small. Margins in a very continuous and similar curve on both sides. Right valve nearly flat and slightly smaller than the other, which is rather more convex, and has coarse, irregular, and sometimes slightly nodulous growth-lines crossing the shell in low curves, so as to be lost in the sides, and not symmetrical with the marginal curve.

*Dimensions*. An unusually large specimen measures  $2\frac{1}{2}$  inches in length.

Three specimens in the Jermyn-Street Museum from Sudely Hill and the *Parkinsoni*-zone of Cheltenham. These specimens are of a neat and regular form, and appear very like Goldfuss's species, to which, I suppose, they belong, but are rather longer, and would appear to have a smaller hinge. A much larger but similarly shaped shell in the British Museum, comes from the Inferior Oolite of Glastonbury. Small oysters are frequent at Dundry, which are coarse and irregular in shape; but it may be that these belong to the same species. If so it would be a very variable shell, and correspond with *O. lingua*, *O. multiformis*, &c. of the higher Jura, *O. Sowerbyi* possibly being an extreme variety.

The Jermyn-Street fossils have two or three longitudinal, parallel, rugose marks on the right valve, not centering in the umbo, but probably taken from some substance of attachment, after the manner, as Mr. Newton pointed out, of *Ostrea irregularis*, Münst.

Whether Terquem's shell is the same may be doubtful, as he states it to be a thin and slightly rayed shell, which does not appear from Goldfuss's figure or description.

**OSTREA EXPLANATA**, Goldf.

1768. *Concha margaritifera*, Knorr, Rec. vol. ii. pt. 1, t. D. 6. figs. 1, 2.

1820. *Ostracites eduliformis*, Schloth. Petref. p. 233 (pars)?

1832. *Ostrea eduliformis*, Ziet. Verst. Württ. t. 45, fig. 1.

1832. *O. Kunkeli*, Ziet. Verst. Württ. t. 48, fig. 1 (fide Oppel).

1834. *O. explanata*, Goldf. Petr. Germ. t. 80, fig. 5.

1834. *O. menoides*, Goldf. Petr. Germ. t. 80, fig. 2.

1836. *O. scapha*, Röm. Verst. nordd. Ool. t. 3, fig. 1.

1857. *O. explanata*, Oppel, Württ. Jahresh. xiii. p. 422.

1858. *O. eduliformis*, Quenst. Jura, p. 430.

1864. *O. explanata*, Seeb. Hann. Jur. p. 92.

1867. *O. cf. eduliformis*, Waagen, in Benecke geogn.-pal. Beitr. vol. i. p. 635.

1867. *O. eduliformis*, Laube, Denkschr. Akad. Wiss. Wien. Band xxvii. Bivalven von Balin, p. 8.

1869. *O. eduliformis*, Brauns, Mittl. Jura, p. 276.

This is a large ovoid flattish shell with a smooth surface, marked only by the usual growth-lines and a few obscure and irregular wrinkles or bulges. It has a large and very transverse ligament, and a large circular muscle-mark. It is less inequilateral than *O. deltoidea*, Sow., and is more convex than that species.

There are specimens in the Bristol Museum from the *Humphriesianus*-zone of Dundry; in the Jermyn-Street Museum from Cleeve Cloud; and in the British Museum from Leckhampton. The last is a very fine fossil, measuring about 5 inches in length. Sharp (Q. J. G. S. vol. xxix. p. 292) quotes a "large, flat species" from the Northampton Sand, Lincolnshire Limestone, and Great Oolite, which is very possibly the same shell.

Its nomenclature seems confused from the doubt whether Zieten was correct in his identification of Schlotheim's shell. Quenstedt, Laube, and Brauns accept his determination, while Oppel supposes it to include another species. D'Orbigny, for some reason, supposes *O. eduliformis*, Schl., and *O. scapha*, Röm., to be synonyms of *G. dilatata*, whereas Schlotheim himself describes that shell as distinct.

Von Seebach quotes it from the "Coronatenschichten," which seem to be equivalent to our *Humphriesianus*-zone; and Oppel gives it as occurring with that Ammonite.

As Schlotheim's shell is stated to come from the "Gryphitenkalk" (=Lower Lias), to be sometimes of the size and shape of a man's head, and to be known as *Ostracites ponderosus*, it would seem that his name was probably a synonym for *Hippopodium ponderosum*, Conyb., and therefore that Goldfuss's name is the proper one to apply to this fossil.

**OSTREA KNORRII**, Voltz. Plate XV. figs. 2; 3, 3 a.

1768. *Ostrea*, sp., Knorr, vol. ii. pt. 2, t. D. 5\*. figs. 5, 6.

1832. *Ostrea Knorrii* (Voltz), Zieten, Verst. Württ. t. 45, fig. 2.

1834. *O. costata* (pars), Goldf. Petr. Germ. t. 72, fig. 8.

1836. *O. costata*, Römer, Verst. ool. Geb. p. 59.



1849. *O. Knorrii*, D'Orb. Prodr. vol. i. p. 257.

1857. *O. Knorrii*, Oppel, Juraform. p. 493.

1858. *O. Knorrii*, Quenst. Jura, t. 66. figs. 37-42.

1864. *O. Knorrii*, Seeb. Hann. Jur. p. 93.

1869. *O. Knorrii*, Brauns, Mittl. Jur. p. 278.

1871. *O. Knorrii*, Terq. & Jourdy, Mém. Soc. Géol. France, ser. 2, vol. xix. p. 133.

This little shell differs from *Ostrea costata*, Sow., by being much more finely and regularly rayed. The rays are more rounded and simpler, and the shell is, as a rule, more convex.

It occurs abundantly in the Inferior Oolite of Bradford Abbas and in the Fuller's Earth near Frome. There are also specimens in the British Museum from the Fuller's Earth of Box, and Von Seebach states that Mr. Day found it in the same beds near Bridport.

Those from the Inferior Oolite seem to attain a larger size than the others; but, as pointed out by Oppel, Terquem, &c., the number and nature of the ribs and its pear-like form render it easily separable from Sowerby's shell, with which Goldfuss has confounded it. Dr. Brauns wrongly identifies it with *O. subrugulosa*, Morr. & Lyc., from which it is very distinct.

The area of attachment is usually small, but occasionally forms a flat surface over the upper half of the shell, and one of my specimens has taken the marks of a *Pecten* over the greatest portion of its exterior. The right valve is smooth and flat in our English examples; and this, which agrees with Quenstedt's definition, throws the only doubt over the correctness of its identification, as Zieten's figures give similar ribs on both valves. As, however, he quotes it from the Fuller's Earth, it may be supposed either that his was an exceptional or aged example, or that there is a mistake in the drawing. This is the more likely, because in *O. costata*, Sow., the flat valve is generally as smooth as he describes it, but in aged examples it is sometimes as strongly ribbed as the other. Moreover, Römer says that in this species it is generally smooth, but sometimes rayed; and Knorr's excellent and characteristic figure also gives it ribbed.

#### *Note on Ostrea costata.*

An inspection of Sowerby's original specimens in the British Museum can leave no doubt of the correctness of Morris & Lycett's determination, the roundness of the ribs to which he refers being very slight, and probably due to the youth of his Ancliff specimens. Larger fossils in the Lycett collection are extremely like miniatures of *O. Marshii*, Sow., and might well be imagined to be the young of that species, were it not that in its early stage it is stated by Morris and Lycett to be almost ribless and akin to *O. sulcifera*, Phill. Again, intermediate between them comes *O. solitaria*, chiefly from the Corallian, though fossils from the Inferior Oolite of Yorkshire are referred to it in the London museums. It seems to have a definite shape and facies of its own, besides being nearly confined

to the Higher Oolites, which would hardly be the case were it a young form of *O. Marshii*, which is common below and rare above, though extending to the Kimmeridgian.

It seems doubtful whether *O. costata* is really found in our Bajocian. Lycett quotes it in the 'Annals,' 1850, from the Oolite Marl of Minchinhampton; and Sharp, in the Quarterly Journal, from Northamptonshire; but the former altogether omits it in his 'Handbook to the Cotteswold Hills.' A small oyster, between *O. costata* and *O. Knorrii*, but distinct from both, is very common in the *Murchisoni*-beds of Crickley, and occurs in those of Minchinhampton. It may be akin to *O. rugosa*, Goldf., as it is nearly smooth at first, though it develops peculiar rounded ribs as it increases in size.

*OSTREA PALMETTA*, Sow., var. *MONTIFORMIS*.

1815. ? *Ostrea palmetta*, Sow. Min. Conch. t. 111. fig. 2.

1834. *O. rastellaris* (Münst.), Goldf. Petr. Germ. t. 74. fig. 8 (pars).

1853. *O. gregaria*, Morr. & Lyc. Gt. Ool. Moll. pt. 2, t. i. fig. 2.

1854. *O. gregaria*, Morr. Cat. Brit. Foss. p. 173.

1871. *O. gregaria*?, Phill. 'Valley of the Thames,' t. 10. fig. 4.

I am unable to believe that the oyster which commonly occurs in our Great and Inferior Oolites, and has been referred to *O. gregaria*, Sow., really belongs to that species. Its size, the precipitousness and irregularity of its ribs, and its gregarious habits seem to define *O. gregaria*. Nor am I satisfied that *O. palmetta*, Sow., is more than a poor specimen of the same; for, from his description, it would appear to have come from the Oxford Clay; but as it has been stated by some to have come from the Great Oolite, I have retained the name for the present.

Morris and Lycett's figure clearly belongs to the shell that occurs at Dundry, Cheltenham, &c.; but it is a highly variable form. Mr. Tawney seems to have joined it to *O. Marshii*, Sow., as he has placed shells of all sizes on a single tablet with that name.

Besides the ordinary forms, I have found shells at Dundry and Crickley which, with another Dundry fossil in the Bristol Museum, seem undistinguishable from the shorter varieties of *O. rastellaris*. These are right valves, with a long, smooth, central convexity, suddenly surrounded by thirty or forty acute, simple, parallel ribs. Their length is about twice their width, and their general shape neat and regular. It is, however, impossible to determine the specific value of so variable a form without a larger number of examples.

*OSTREA PYRUS*, n. sp. Plate XV. figs. 4, 4a.

Shell small, long, very narrow, the length from the umbo being nearly twice the breadth; very deep below, the greatest depth being just over the inferior margin.

Umbo of left valve small, acute, and terminal, with an acutely triangular ligamental groove; surface smooth.

The surface of attachment runs down the centre of the shell, and is, in all instances, long, narrow, and very concave, as though it had

been attached to a long Polyzoan, Encrinite, or some such object. The general shape is that of a slightly squared and oblique pear, the anterior edge being squarely convex, the posterior straight, the inferior straight, but curving suddenly to meet the lateral parts. The back is flat, and the three sides are so steep as to be nearly perpendicular to the marginal plane. The surface has one or two irregular and indistinct growth-swellings, but is otherwise smooth, except for a few accidental bulges.

There are several specimens of this shell in the Sharp Collection in the British Museum, from the "Barnack Rag."

Mr. Sharp's fossils have been labelled "*Ostrea sulcifera*, Ph. = *Ostrea flabelloides*, jun." It does not seem at all similar to either of these species. It shows no sign of radiation, is of quite a different size and shape, and has always very steep deep sides, whereas the sides of *O. Marshii*, Sow. = *O. flabelloides*, Lam., are essentially flat. In Brown's 'Fossil Conchology' a similar shell is figured and described as *O. sulcifera*. *Gryphæa mimæ*, Phill. Geol. Yorksh. vol. i. t. 4. fig. 6, is a very much more transverse and undefined shell.

The largest specimen measures 7 lines in length by 4 in breadth and 2 in depth. The others are decidedly smaller; some are comparatively wider, but in these instances they seem to be deformed.

**OSTREA SPHÆROIDALIS, n. sp.** Plate XV. figs. 5, 6.

Left valve large, hemispherical, smooth. Umbo small, central, prominent, and compressed. Hinge-margin wide, nearly straight. Ligamental groove large, much wider than long. Shell thin, very convex, but flattened on each side of the umbo, so as to form two indistinct wings. Surface with laminar growth-bulges. Muscle-mark rather small, circular, and subcentral. Right valve flat.

*Size.*  $2\frac{3}{4}$  inches in length and width, and 1 inch in depth.

This handsome and well-characterized oyster is common in the shelly bed at the base of the Inferior Oolite near Yeovil Junction.

**GRYPHÆA ABRUPTA, n. sp.** Plate XV. figs. 7, 7 a.

Shell very convex, triangular, inequivalved. Left valve divided into two portions by a small deep groove starting from the surface of attachment, and running obliquely down the shell. The part of the shell anterior to this equals two thirds of the whole surface, and is regularly convex; the portion posterior to it first swells out into a straight rounded ridge (starting nearly from the umbo, and bordering the groove), along which is the greatest diameter of the shell, and immediately behind this the surface is so suddenly depressed and flattened that it cuts the marginal plane almost at right angles on the posterior side. The umbo is large and well developed, but truncated by a small flat surface of attachment, which seems always to occupy a similar position on the shell. The shell is smooth and thin compared with that of *G. sublobata* (Desh.), and shows occasional irregular lines of growth.

Length 2 inches, width  $1\frac{1}{2}$  inch, depth 10 lines.

Three specimens in the Bristol Museum and one in my collection from Dundry.

Mr. Tawney considered this form to be new; and I am aware of no described species that approaches it. In shape and style it mimics *Trigonia costata*, Park., in a curiously striking way.

*GRYPHÆA CYGNOIDES*, n. sp. Plate XV. figs. 8, 8a.

Shell narrow, subtriangular, much inflated. Umbo very prominent and elongated, narrow and much incurved, arching regularly round, with the point inclining and facing backwards; covered with ten or twelve coarse irregular rounded rays or frills over the recurved portion, which are about half an inch long, and vanish rather suddenly, leaving the rest of the shell smooth, except for fifteen or twenty very irregular and well-developed growth-edges at nearly equal distances over the rest of the shell. Surface divided into two very unequal lobes by a very strong sulcus, which reaches the umbo. Posterior lobe very convex, narrow, and only slightly increasing in width downwards.

Length 3 inches, breadth 2 inches.

*Locality.* Broadwindsor. One specimen in the British Museum and one in my collection.

The left valve is just like that of *G. incurva* (Sow.), to which the present shell bears much resemblance, except that the umbo is narrower and more highly arched, and that the greatest length is much nearer the inferior margin, which is much straighter and less convex than in *G. incurva*.

*G. calceola*, Quenst. Jura, t. 48. fig. 1, is very similar, but differs by having no plaits on the apex, and by the umbo being even more arched and enlarged. It may, however, be possibly only a variety of this shell.

*GRYPHÆA CYMBIUM*, Lam.

1819. *Gryphœa cymbium*, Lam. Anim. s. Vert. vol. vi. p. 198.

1834. *G. cymbium*, Goldf. Petr. Germ. t. 85. fig. 1.

1849. *G. cymbium*, D'Orb. Prodr. vol. i. p. 238.

1852. *G. cymbium*, Buv. Stat. Géol. de la Meuse, t. 5. figs. 5, 6, 7.

1853. *G. cymbium*, Chap. & Dew. Foss. Lux. pt. 1. t. 33, fig. 1, and t. 34. fig. 1.

1854. *G. cymbium*, Morris, Cat. Brit. Foss. p. 168.

1854. *G. cymbium*, Brown, Foss. Conch. t. 61, figs. 22, 23.

There is a fine specimen of this Middle Lias form from the *Humphriesianus*-zone of Dundry in the Bristol Museum. It is an elongate, pear-shaped, convex, left valve, with an indistinct sulcus forming an unprojecting wing, and a large curved umbo bending backward. It comes exactly between two ordinary Middle Lias specimens in the same museum.

It was identified by Mr. Tawney, who has added a note to it, "Certainly from Dundry, as labelled," in which assertion, after examining the matrix, I believe him to be right.

It is possible to imagine it a remanié shell from the Lias, as the



species is a very strong and massive one; but the specimen is quite as well preserved as the usual run of fossils from the same beds.

Sowerby quotes it as from the Inferior Oolite, but gives as its locality Ilminster, where it is found in the Middle Lias.

*GRYPHÆA SOLLASII*, n. sp. Plate XV. figs. 9, 9 a.

Left valve deep and evenly convex, with a slight irregular depression running slantways across it from the front of the umbo backwards, which may be accidental rather than indicative of a lobe. Umbo small and but slightly developed, and curving half-way round, so as to approach *Exogyra*. Lines of growth irregular, bearing occasional impressions of sharp thorn-like spines in the marginal regions. Marginal curve deep and continuous.

Right valve very thick and flat, with a short, straight hinge-line, which shows the nucleus of the umbo at the extreme anterior corner.

*Locality.* Dundry. One specimen in the Bristol Museum.

*Dimensions.* 21 lines long, 15 wide, and 9 deep.

*Gryphæa plicata*, Lyc. Ann. & Mag. Nat. Hist. 1850, and Brown, Foss. Conch. p. 149, and t. 61. figs. 26-28, is quite a different shell.

*EXOGYRA DAVIDSONI*, n. sp. Plate XV. figs. 10, 10 a.

Left valve large, convex, smooth. Umbo proximate and very much curved backward over the hinge-margin. Surface of attachment large. Substance of shell lamellar, thin towards the margins. Hinge-line very large. Surface covered by fine and irregular growth-marks. Convexity greatest along the central line of the shell, where it forms a rounded ridge with steep sides, which arches very rapidly down to the umbo.

*Dimensions.* About  $2\frac{1}{2}$  inches long, 2 inches wide, and 1 inch deep.

This fine fossil is from the Inferior Oolite of Frocester Hill, and it appears to be a well-marked species, somewhat like *Exogyra sinuata*, Sow., of the Greensand, but steeper. The hind margin of my specimen is unfortunately defective. It was apparently attached to another specimen of the same species. The sandy beds from which it comes appear to belong to the lower part of the *Murchisoni*-zone.

Chapuis & Dewalque, in Foss. Lux. pt. 1, t. 32. fig. 5, figure an *Exogyra* something similar but much smaller as *O. arcuata*, Lam., var. *suilla*, Schl., referring to Goldfuss. Goldfuss's figure, however, of *O. suilla* is quite unlike our shell; and a Norman specimen in the British Museum shows it to be rightly classed as a *Gryphæa*.

*EXOGYRUS GLOBULUS*, n. sp. Plate XV. figs. 11, 11 a.

Shell small. Left valve with the surface rather indistinctly nodulous, very convex, forming a sharply rounded ridge near the centre of the valve, from which the anterior side slopes down at an angle of  $45^\circ$ , and the posterior at about  $15^\circ$  from the perpendicular. Margins forming an almost complete circle, so that the depth equals the length, and is a little less than the width. Umbo small but well developed, concave posteriorly, the central ridge becoming on it a

raised spiral edge. Muscle-mark circular, almost in the exact centre of the posterior aspect.

From the lower green bed of the Northamptonshire Oolite. Two specimens in the Sharp Collection in the British Museum, probably from Duston.

*Dimensions.* 4 lines.

The only remaining parts are moulds of the left valves. Its distinct reflected umbo at once distinguishes it from *G. mima*, Phill., while, according to Morris & Lycett, *Exogyra auriformis*, Goldf., has a large adhering surface on its left valve, and its right valve has a flat and subspiral but very much larger umbo.

*Exogyra lingulata*, Morr. & Lyc. pt. 2, t. 32. fig. 2, is a much longer, narrower, and larger shell. Brown, however, in his 'Fossil Conchology,' t. 61. figs. 10-12, and p. 149, gives a shell which is much nearer the present species. This shell, *Gryphæa minuta*, Sow., Min. Conch. t. 547. fig. 4, as figured and described in Lycett's Supplement, differs by having a much larger and more direct beak, which is "closely pressed," and a more rounded and flatter surface. Though Sowerby's own figures are more like, his original specimens in the British Museum show that though it is an *Exogyra*, its umbo is much more terminal, and its anterior side more expanded, so that its mould would be flatter and less defined.

*PLACUNA RUPERTINA*, n. sp. Plate XV. figs. 16, 16 a.

Left valve convex, very thin. Hinge-line small, wide, edentulous, transversely striated. Cartilage-grooves small, narrow, concave, equal, each inclined at an angle of more than  $45^\circ$  to the perpendicular. Between these and the hinge are two oblique raised spaces or rounded ridges penetrating the general concavity of the interior for a short distance. Muscular impression long, narrow, but slightly expanding as it extends from the hinge two thirds down the centre of the shell, where it ends with a slight curve forwards, and defined by a slightly raised boundary line. Umbo acute. Hinge-area bounded by short straight lines. Anterior margin very convex, posterior nearly straight, postero-inferior corner subangular. Surface most convex near posterior side.

*Dimensions.* Length 3 inches, width  $2\frac{3}{4}$  inches, depth 1 inch.

One specimen in the Sharp collection in the British Museum, from the Inferior Oolite of Duston.

This specimen is only a cast, but it appears to give all the characters of the shell except the exterior markings, and to be so remarkable as to be worth noticing. It does not belong to Lycett's genus *Placunopsis*, which differs in having a single and central cartilage-groove, and in the style of the muscular impression, while the species described by him under that genus are all very much smaller and of different contour.

On the other hand, Prof. Rupert Jones (after whom I have the pleasure of naming it) having labelled it "allied to *Placuna* of Indian and Chinese seas," and Mr. Etheridge having very kindly compared it with recent specimens, there remains, I think, no doubt that it

belongs to that genus. It has the same cartilage-grooves, wide hinge, and thin test; and, on the presumption that the lines between the horse-shoe anterior mark, the circular posterior one, and those joining the latter with the hinge in the recent shell, are lost or almost imperceptible in the fossil cast, there is almost exact agreement in the muscular impressions.

*PLACUNA SAGITTALIS*, n. sp. Plate XV. fig. 17.

Right valve elongated, oblique, longitudinally flat, transversely convex. Apex small, posterior, facing backwards, marginal, not raised above the surface of the shell. Hinge-margin nearly straight, the posterior part much shorter than the anterior, and inclined at a slight angle to it. Shell transparent, very thin. Hinge-markings visible through the shell; two long (4 lines), narrow, oblong, cartilage ridges, meeting at an angle of about  $45^\circ$ , between which are possibly small ones bounding a concave groove. Surface covered by very crowded and fine concentric thread-like striæ which become waved near the margins, and more distant and regular lines of growth. On the lower part are numerous very indistinct and broken longitudinal swellings, and a few rows of distant cavities, like reversed arrow-heads, which tend to form radiations.

*Locality.* Dundry. I have only obtained a single specimen.

*Dimensions.* Length 16 lines, width 16, depth 2.

On one portion of the surface is a possibly attached fragmentary surface of plain shell, covered by numerous minute ovals, which may represent fry.

*Placunopsis oblonga*, Laube, 'Bivalven von Balin,' t. 1, fig. 8, closely approximates to it, but is finely radiated, and differs in the size and position of the umbo.

*PLACUNOPSIS SEMISTRIATA*, Bean, sp.

1839. *Anomia semistriata*, Bean. Mag. Nat. Hist. 1839, p. 61, fig. 21.

1863. *Placunopsis semistriatus*, Lyc. Suppl. Moll. t. 33. figs. 9, 9a.

I have found a specimen of this shell in the interior of *Terebratulina perovalis* at Dundry, in the same way as those described from the north of England.

*PECTEN ARATUS*, Waagen.

1867. *Pecten aratus*, Waag., in Benecke's geogn.-pal. Beitr. t. 31. fig. 4.

This large, round, and flat shell is distinguished from *P. lens*, Sow., by the multitudinous and finely radiating river-like markings of the eared valve, which continually bifurcate and often disappear as they approach the margins. From *P. cinctus*, Sow., it is also distinguished by the absence of the regular lines of growth and by its very much smaller size.

The other valve is also flat. Its central part is covered with circles of very coarse puncta, which coalesce into an irregular zigzag

ornamentation in the more distinct portions, and become radial at the margins.

There are specimens in the Bristol Museum from the *Humphriesianus*-zone of Dundry, in the Jermyn-Street Museum, from near Grantham, and in the British Museum from Northamptonshire and the Lower Trigonina-Grit of Leckhampton.

The species was originally described from the *Sowerbyi*-zone of Gingen.

It seems to be a very variable shell both in shape and markings. The left valve is sometimes marked similarly to the right, and sometimes the radiations almost entirely disappear.

A fossil in the Sowerby Collection seems to belong to this species.

PECTEN CORNUTUS, Quenst. Pl. XVI. figs. 1, 2, 2a.

1852. *Pecten cingulatus*, Quenst. Handb. t. 40. fig. 41.

1858. *P. cornutus*, Quenst. Jura, t. 74. fig. 10.

Each valve smooth, nearly flat, rather longer than wide, ornamented interiorly by nine or ten rounded radiations, which terminate abruptly before reaching the margin. Right valve with anterior ear moderately notched, posterior ear rather larger. Left valve with ears equal, produced triangularly beyond the umbo, and covered beneath with fine longitudinal striæ.

This shell was at first described by Quenstedt as the *P. cingulatus* of Phillips, Geol. of Yorkshire, tab. 5. fig. 11, quoted and figured by Goldfuss on his plate 99. fig. 3 (though the English author himself gives no name in his edition of 1829). In his "Jura," however, he correctly distinguished it, and called it *P. cornutus*, on account of the horn-like wings. Its internal rays at once separate it from *P. demissus*, Phill.

In the Jermyn-Street Museum there are fine specimens of both valves from Bridport, only differing from Quenstedt's figure by being slightly wider, and having, perhaps, less elongated horns. Another from Leckhampton, probably belonging to the same species, has much longer horns, marked at the base by two sharp transverse ridges. As its surface shows some slight signs of tessellation, some of the small specimens common at Dundry and the Cotteswolds, and usually classed as *P. personatus*, Goldf., may, from their likeness to it, eventually prove to be the young of this form.

PECTEN DEMISSUS, Phill. Pl. XV. fig. 15.

1829. *Pecten demissus*, Phillips, Geol. Yorksh. vol. i. t. 6. fig. 5.

1835. *P. demissus*, Goldfuss, Petr. Germ. t. 99. fig. 2.

1836. ? *P. vitreus*, Röm. Verst. ool. Geb. t. 13. fig. 7.

1849. *P. demissus*, D'Orb. Prodr. sect. 12, no. 214.

1853. *P. demissus*, Lyc. & Morr. Gt. Ool. Moll. pt. 2, t. 14. fig. 7.

1858. *P. demissus*, Quenst. Jura, t. 44. fig. 14.

1864. *P. demissus*, Seeb. Hann. Jur. p. 101.

1869. *P. demissus*, Brauns, Mittl. Jur. p. 270.

This species, which is common and often very large at Dundry, and occurs in the *Parkinsoni*-zone of the Cotteswolds and at Broad-



windsor as well as in the Northampton Sands and Lincolnshire Limestone, has a very wide upward range through the Great Oolite, the Cornbrash, and the Kelloways to the Coral Rag.

D'Orbigny gives *P. vitreus*, Röm., as a synonym. This shell is much more circular than the usual figures of *P. demissus* (vide Phill.), and appears to approach *P. disciformis*, Schübl., as figured by Chapuis & Dewalque (pt. 1, t. 31. fig. 2), which, however, seems equal to *P. corneus*, Sow. The last-named authors, in fact, unite *P. corneus* and *P. demissus* of Goldfuss (non Sow. or Phill.), stating that they only differ in "the shape of the wings, which is not a constant character." Waagen, again, seems to consider our shell distinct from *P. disciformis*, with which Brauns unites it as well as with *P. spathulosus*, Röm. (a very distinct shell), and doubtfully with *P. cingulatus*, Goldf., pars, non Phil.

A variety (v. *inutilis*, nobis) occurs commonly in the *Jurensis*-zone of Yeovil Junction, and often shows very beautiful zigzag colour-markings, as in the fragment figured. As it has larger ears, and seems more convex and oblique than the ordinary type, I am uncertain whether it may not prove to be a distinct species.

Another variety (v. *celatus*, nobis) is represented by a shell in the British Museum, from Gayton. It is apparently smooth, but, under a lens, it is seen to have several fine, rounded, evanescent radiations in its central region. I have little doubt that if further material were forthcoming, it would be found to be a distinct shell, as I have met with nothing at all resembling its ornamentation. The matrix is dark sandstone, and the shell itself is coloured a bright brownish red, without markings.

Several instances of the preservation of colouring are found among English Jurassic shells. *Pecten valoniensis*, Defr., of the Infraliassic beds of Aust, sometimes retains most vividly its brown, blue, and white tints; and *P. similis*, Sow. ?, of the Coral Rag, its dull fawn-colour. The brown and white colour-bands of *Cyprina picta*, Lyc., of the *Murchisoni*-zone in the Cotteswolds, are noted in Ann. & Mag. N. H. 1850, p. 423; and a similar decoration is sometimes seen in *Lima strigillata*, Laube. At Minchinhampton both *Nerita rugosa* and *Nerita hemisphærica* are often found retaining dark brown bands, and a figure of *Nerita costulata*, Sow., v. *bicincta*, Ph., banded with white and purple, is given by Phillips in his 'Valley of the Thames'; while Walford describes the tints of *Natica cincta*, and has informed me that he has often noticed remains of colour-bands in a *Pecten* cf. *demissus* from his "Transition Bed" of the Middle Lias of Banbury. Traces of delicate purple may be seen in a specimen of *Hinnites velatus* in the British Museum; and *Rhynchonella radstockiensis* may be frequently collected of a very decided dark red hue.

#### PECTEN GINGENSIS, Quenst.

1858. *Pecten demissus gingensis*, Quenst. Jura, t. 51. fig. 8.

1867. *P. gingensis*, Waagen in Benecke's geogn.-pal. Beitr. vol. i. p. 629.

There is a specimen of this shell in the British Museum from the Green bed of the Northampton Sand of Casterton, and it is quoted by Sharp from the Lincolnshire Limestone.

It is distinguished from *P. demissus* by its greater width, more symmetrical and equilateral contour, and the shape of the wings.

*PECTEN FENESTRALIS*, n. sp. Plate XV. figs. 12, 12a.

Right valve flatly convex, slightly oblique. Wings defective, but apparently rather large, and the front one very lobate. Umbo flat, small, acute, and narrow, bounded on each side by long concave edges, over which the surface turns through a right angle and reaches the plane of the wings at about the depth of half a line below them; these edges reach the circumference of the shell at less than half its diameter from the umbo, the margins then forming a regular semicircular curve, a little produced, however, in the infero-anterior direction. The whole surface ornamented by about twenty-five prominent, distant, subacute, straight rays, which have a tendency to alternate, and are crossed by rather more numerous and smaller, sharp, fringe-like ridges, forming with the rays small hollows, which are either square or have their shorter and not their longer diameter (as in *P. retiferus*, M. & L.) in the direction of the rays. The central region somewhat convex, becoming slightly concave near the sides. The inside with ten or twelve smooth rays (as in *P. personatus*).

*Dimensions of Right Valve.* Length 11 lines, width 10 lines, depth 1 line.

There is a specimen of the right valve in the Lycett Collection at Jermyn Street, from Rodborough, and I have obtained similar shells at Dundry, Leckhampton?, and Bradford Abbas.

In *P. clathratus*, where a similar but much finer network occurs on the right valve, the number of rays is more than sixty, and they are all of the same size, slightly but distinctly undulating. The concentric ridges also are of the same size as the rays, the shell is much longer and less oblique, the marginal curve is greater than a semicircle, and the side edges by the ears are straight and not so prominent. The shell is much flatter, the umbo small and less elevated, and the ears probably larger.

In the left valve of *P. retiferus* the rays are rounded on the top and much more numerous, and are cut and broken by the irregular turned-up and lamellar edges of the very distant growth-lines. It is a much more convex and equilateral shell, and the side ridges are indistinct.

In the present species the difference in the size of the alternate rays is sometimes very marked, and the transverse fringes, being very fine, are often rubbed or broken off.

*PECTEN INTERMITTENS*, n. sp. Plate XV. figs. 13, 13a.

Right valve somewhat convex, longer than wide. Umbo direct, central, bounded by two low, oblique, straight ridges, which meet the border one half way down the diameter of the shell. Anterior

ear small; posterior moderate, somewhat acute. Ears ornamented with transverse markings. Surface with about twenty-two low, distant, indistinct ribs, crossed by numerous raised, thread-like, concentric threads, which are elevated by the ribs in the front part of the shell, while on the hinder part two adjacent ones generally unite on the top of each rib to form a larger and higher bar (fig. 13 a).

One specimen in my collection from the *Clypeus*-Grit of Birdlip.

*Dimensions.* Length 7 lines, width 6 lines.

I am acquainted with no other Oolitic *Pecten* having a similar ornamentation.

#### PECTEN LÆVIRADIATUS, Waagen.

1867. *Pecten læviradiatus*, Waagen in Benecke's geogn.-pal. Beitr. vol. i. tab. 31. fig. 4.

This is a flat circular shell with twenty or thirty distant, sharp, triangular ribs, alternating in size, and with no other markings except crowded microscopical concentric lineations, and sometimes a single line of growth.

The Jermyn-Street Museum possesses specimens of it from Bradford Abbas, and I have collected it from Dundry, Mosterton, the Oolitic sands of Bridport, and the *Jurensis*-zone of Yeovil Junction. The original specimen was from the *Sowerbyi*-zone of Gingen, in Württemberg. Some small and rather more convex shells at Jermyn Street, from "the bottom bed of sand N.E. of Cheltenham," may be the young form of this species. In them the transverse markings are rather more prominent and the flat valve is smooth.

#### PECTEN PUELLARIS, n. sp. Plate XIX. figs. 3, 3 a.

Shell small, orbicular, roundly convex, equilateral. Umbo large, central, rounded, incurved, and extending above the hinge-line. Ears small (the front one being rather the larger), obtuse, marked with three flat rays and about fifteen raised rounded threads. Surface covered by about twenty raised, rounded, narrow, and distant smooth rays, half of which reach and curve over the umbo, and half vanish in the grooves about three fourths of the way up. Grooves concave, nearly twice the width of the rays, and crossed by very distant, fine, sharp threads, which are concave to the apex. Margin circular, scalloped by the projection of the grooves.

Size 5 lines long, by 5 broad, and 2 deep.

The only specimen I have seen of this beautiful little shell is in the British Museum, and comes from the Inferior Oolite near Northampton. From *P. symmetricus*, Morris, Hull's 'Geology of Cheltenham,' t. 1. fig. 3, it differs by the width of its grooves; from *P. subspinosus*, Schl., Goldf. Petr. Germ. t. 90. fig. 3 (specimens of which from the Inferior Oolite of Brimscombe are in the Jermyn-Street Museum), by the number of rays and absence of spines; and from *P. anomalus*, Terq. & Jour. Mém. Soc. Géol. Fr. sér. 2, vol. ix. t. 13. figs. 18-20, by its ungrouped costæ. In neither of these species are there any signs of the alternation of the rays, which would appear to be very characteristic of the present shell.

PECTEN SPINICOSTATUS, Eth. MSS., n. sp. Plate XV. figs. 14, 14a.

Shell orbicular, very convex, equilateral. Umbo direct, very prominent, raised, large, and bluntly rounded. Ridges above wings very distinct, short, very low, and concave. The other margins almost evenly circular, except that they are crenulated by the projecting furrows, meeting the horizontal plane at an angle of about 45°. Surface evenly convex, but slightly produced and flattened on the anterior side. The anterior ear very large and acutely triangular, with five or six large and very coarsely corrugated rays or ribs. The right valve covered with about forty-five very steep ribs, flat and smooth on the tops, bearing a row of distant, regular, oblique spines on each side, close to the flattened summits. The furrows slightly narrower than the ribs, covered with close, fine, distinct, thread-like concentric lines, which are concave to the umbo.

*Locality.* Dundry. One specimen in the British Museum; several in that of the Bristol Institution. I have collected several from the beds above the Ironstone Oolite, belonging to the higher part of the *Humphriesianus*-zone; but in most cases these fossils are much injured, showing that it was probably a fragile shell.

*Dimensions of each Valve.* 13 lines in length, 12 in width, and about 5 in depth.

This shell approaches *Pecten globosus*, Quenst. Jura, p. 757, *Pecten cardinatus*, Quenst. Jura, p. 627, and *P. moreanus*, Buvignier, Meuse, t. 19. figs. 18–20, which are all similarly decorated.

From the first it appears to differ by having fewer and coarser rays; from the second by having the furrows broader and the ray-teeth blunter and more distant; and from the third by not having these side ornamentations raised above the level of the rays. It also appears to have a less developed or produced umbo than the two former shells; Thurmann and Etallon give a better figure of *P. globosus*, Quenst. All these species seem to be more globose shells, with more depressed umbones than the British species. *P. erinaceus*, Buvignier, Meuse, t. 19. figs. 7–12, is a flatter shell, and has a third row of spines on each rib. The foreign species occur in the Middle and Upper Oolites.

The small group of *Pecten*s to which this shell belongs are very distinct, being all more or less convex, and having the ribs marked by rows of very beautiful spines or teeth, which are clearly not due to fossilization. They differ from the group to which *P. articulatus* belongs by the ribs being much more flattened on the top.

PECTEN TRIFORMIS, n. sp. Plate XVI. fig. 3.

Shell large, moderately convex, inequilateral, suborbicular. Umbones large, direct, rather produced. Superior part of posterior side more enlarged than anterior. Surface covered with fine, parallel, sharply zigzagging lines in the central part; beyond these with very fine close excentric radiating striæ; and in the marginal parts with distant thread-like concentric lines or annuli, which present a frill-



like appearance, caused by short radiating lines upon each ring. Wings small.

There is one specimen in the Sharp Collection in the British Museum, from Northamptonshire; and, though very defective, its ornamentation is so peculiar as to be worth recording. It is about 3 inches long.

*HINNITES TENUISTRIATUS*, Münst., sp.

1836. *Spondylus tenuistriatus*, Goldf. Petr. Germ. t. 105. fig. 3.

Left valve small, nearly circular, slightly convex, with prominent umbo, and about thirty-five squared ribs divided by flat interspaces of nearly the same width. The ribs are occasionally nodulated upon their upper surfaces, and only the alternate ones reach the umbo. Auricle distinct.

Size about half an inch.

I have obtained several specimens of this fossil from the rubbly beds at the top of the *Humphriesianus*-zone at Dundry, and from the *Parkinsoni*-zone of Burton Bradstock.

It appears to differ from *Hinnites velatus*, Goldf., as figured by Morris and Lycett, by having larger and more equal rays, as well as by being a smaller shell; but in the former particular their figure (though not their description) approaches the present species more nearly than does the original one of Goldfuss.

*LIMA RIGIDA*, Sow., sp.

1815. *Plagiostoma rigidum*, Sow. Min. Conch. t. 114. fig. 1.

1835. *Lima rigida*, Goldf. Petr. Germ. t. 101. fig. 7.

1861. *L. rigida*, Thurm. & Et. Leth. Bruntr. t. 33. fig. 2.

1861. *L. perrigida*, Thurm. & Et. Leth. Bruntr. t. 33. fig. 1.

1864. *L. rigida*, Seeb. Hann. Jura, p. 102.

In the Bristol Museum are some shells from Dundry, which were identified with this species by Mr. Tawney, and there is a similar one from Leckhampton in the Jermyn-Street collection.

Of the two fine specimens in Sowerby's collection, one is of a deep red colour, with hardly any signs of growth-lines, while the other has very strong growth-lines, which break the continuity of the rays; but as they closely correspond in other respects, I can see no reason for supposing them to be of different species, and believe that it would be easy to arrange a series of Inferior-Oolite specimens connecting the two.

*LIMA CERYBOLUS*, n. sp. Plate XVII. figs. 1, 1a.

Shell flatly convex, oblique, semielliptic. Umbo small, depressed, rounded. Lima-line\* short, low and rounded; the shell curving round in front of it so as to form a moderately concave lunule, and behind it being regularly, though slightly, convex, so that the greatest depth is nearly in the centre of the valve. Front wing of moderate size and flattened. The margin from its summit forming a concavity with the anterior side of the shell; the inferior side slightly

\* I have used this term, for convenience, to indicate the strong bounding ridge of the lunule, which is so marked a feature in most species of *Lima*.

and regularly convex; the posterior side much more convex; but the curves are very even ones, without sudden changes of curvature. Surface with about fifty high, narrow, acute and distant ribs, with rounded tops and perpendicular sides, cut by three or four sharp growth-lines near the margin, and separated by flat broad furrows three or four times the width of the ribs, which are crossed by very distinct and numerous, long, ladder-like striæ, convex towards the umbo.

One specimen in the Jermyn-Street Museum, from Broadwindsor.

*Dimensions.* About 3 inches long, by  $2\frac{1}{4}$  wide, and 1 deep (for both valves).

It approaches *Lima Renevieri*, Etallon, Leth. Bruntr. t. 34. f. 4, but is a much less convex shell, and differs from both that shell and from *L. notata*, Münster., by the extremely narrow and perpendicular ribs with which it is covered.

#### LIMA ALTICOSTA, Chap. & Dew.

1853. *Lima alticosta*, Chapuis & Dewalque, Foss. Terr. Sec. Lux. t. 28. fig. 3.

1858. *Plagiostoma sulcatum gingense*, Quenst. Jura, t. 51. fig. 2.

1867. *Lima alticosta*, Waagen, in Benecke's geogn.-pal. Beitr. p. 625.

There are specimens of this shell in the Bristol Museum, from the upper part of the *Humphriesianus*-zone of Dundry (from which place I have myself obtained it), and in the Jermyn-Street Museum, from Yeovil and Rodborough.

It differs from *Lima pontonis*, Lycett, Quart. Journ. Geol. Soc. vol. x. t. 14. fig. 2, in being much less transverse.

#### LIMA AMNIFERA, n. sp. Plate XVII. fig. 2.

Shell very flat, oblique, ovoid, transverse. Umbones small, acute, elevated, and very slightly incurved. Lima-line short and low. Ears small, dilate, receding, and nearly equal. Lunule small and slightly concave. Antero-inferior margin roundly convex, the marginal curve gradually decreasing towards the posterior border, which becomes somewhat concave in forming the ear. Surface moderately convex behind the lima-line, and flattening out from the centre to the other edges, which meet at a very small angle; covered with frequent but irregular concentric growth-lines, and radiated by very numerous (seventy) slightly undulating, impressed lines of very coarse and distant puncta, which vanish towards the central portions of the shell.

*Dimensions.* 22 lines long, by 17 wide, and 6 lines deep for the closed valves.

This species occurs abundantly in the beds of the *Jurensis*-zone below the sands at Yeovil Junction, and sometimes gives indications of concentric colour-bands. There are three specimens from that place in the Jermyn-Street Museum.

It is very similar to *Lima aciculata*, Münster., but differs in the size and shape of its posterior wing, in its less orbicular form, and in

the greater indistinctness of its markings. As Goldfuss, Thurman and Etallon, and Chapuis and Dewalque all give the same characters for the latter shell, I have thought it better to distinguish the present one, although at first inclined to agree with others in supposing it to belong to *L. aciculata*. The individuals do not seem to vary much, but preserve their common characteristics. It approaches *L. ovalis*, Sow., but is flatter and less transverse, besides having more defined ears than that shell. It also very much resembles *Lima pseudovalis*, Waagen, in Benecke's geogn.-pal. Beitr. vol. i. t. 30. fig. 3, but is distinguishable by the presence of well-defined ears, by being flatter and anteriorly broader, by having more distant and less incurved umbones, and by not having narrow and elevated ribs.

*LIMA CONTORQUENS*, n. sp. Plate XVII. figs. 3, 3a, 3b.

Shell moderately convex, flattened near hind margin; valves meeting at a moderate angle. Umbo very posterior, facing anteriorly, pointed and incurved. Lima-line rather indistinct, concave anteriorly, about three fourths of the length of the shell in that direction. Lunule very deep and concave. Posterior wing narrow, ill-defined, rendered rugose by crowded growth-lines. Greatest concavity about one third behind the lima-line. Inferior margin nearly semicircular. Ribs about 60, undulating, flattened, depressed, divided only by shallow, but very distinct, undulating, linear, punctate channels. Ribs often having a second indistinct channel on their flat tops, so as to be somewhat dichotomous. Growth-lines distant, regular, small and white.

One specimen in the Sharp Collection in the British Museum.

*Dimensions.* 16 lines long, by 13 wide, and 6 deep (for both valves).

This shell has much less obliquity than most *Limæ* of the Inferior Oolite. It is very similar to *Lima comatula*, Buv. Meuse, t. 18. figs. 20-25, but has a sharper beak, and more distinct posterior ear; its posterior side is much less dilate, its lunule longer, and its rays fewer. *Lima semilunaris*, Goldf. Petr. Germ. t. 102. fig. 2, is a much more contorted shell, without a distinct lunule, and rayed only on the sides.

*LIMA CUBIFERENS*, n. sp.

Shell elongate, ovoid, slightly oblique, and very flat. Umbo acute, proximate, subcentral. No lima-line or lunule. Wings large, equal, and triangular. Anterior wing covered by rugose growth-lines. Margin slightly concave below anterior wing, convex in the antero-inferior region, and then proceeding in a low curve to the posterior part, where it becomes strongly convex before reaching the other wing. Ornamentation consisting of about forty very distant threads or ridges, crossed by very numerous, foliaceous, concentric ridges, which were evidently freely lamellar towards the margins.

*Dimensions.* 33 lines long, by 25 wide, and 12 deep.

There are three specimens in the British Museum, one from the

"Marly bed, Down Cliff, Dorset," and two from the Limestone and Upper beds of Duston.

It belongs to the same group as *L. rigidula*, Phill. (*non* Morris and Lycett?), and *L. antiquata*, Sow. Sowerby's shell differs from it in the character of its radiations, which are close and rounded, as seen in his figured specimen from the middle Lias in the Bristol Museum. *L. antiquata*, Münster, Goldf. t. 102. fig. 14, seems to be distinct from this, and more nearly approaches the present form, but is unlike it in its convexity, its smaller ears, its inconsecutive rays, and its distant, prominent, concentric ridges. *L. rigidula*, Phill. (*not* Morris and Lycett), though possibly the same as Münster's species, appears from the figure (Geol. Yorksh. vol. i. t. 7. fig. 13) to be much more curved and convex than the present species, with stronger and closer ribs, and a much longer anterior ear. *Lima succincta*, Schl., is given by Giebel as a synonym of *Lima Hermannii*, which is very dissimilar both in contour and in decoration.

LIMA EDUCTA, n. sp. Plate XVII. figs. 4, 4a.

Shell small, oblique, moderately convex, very transverse. Umbo acute, prominent but attenuated, very distant, and very posterior. Wings small, narrow, nearly equal, and marked by the lines of growth. Lima-line depressed, nearly the length of the shell in that direction. Lunule smooth and concave. Greatest depth at the point one third from the lima-line and one third from the umbo. Inferior margin moderately convex; the curve deepening very much round the infero-posterior, and still more round the infero-anterior portions. The apical part of the surface smooth, the rest covered with very fine elevated and undulating ribs with flattened tops, which are divided by narrower smooth grooves and broken by occasional well-defined growth-lines which cause them to change their direction.

*Dimensions.* Length 13 lines, breadth 9 lines.

There is a specimen of this shell in Jermyn Street, from the *Parkinsoni*-zone of Leckhampton, and another in the British Museum, from Dundry; and I have one from the *Humphriesianus*-zone of Cleve Cloud.

This shell is quite different from *L. ovalis*, as figured by Goldfuss and by Morris and Lycett, and from the Minchinhampton and Inferior-Oolite form which they represent. The two original specimens, however, in the Sowerby Collection in the British Museum seem different, and one of them very nearly approaches the present species, though differing from it in the size of the punctations, while the other is clearly distinct both in its contour and ornamentation. Our shell is totally unlike *Lima rigidula*, Phill., Geol. Yorksh. vol. i. t. 7. fig. 13, which is a different species from that figured by Morris and Lycett under that name. The latter much more nearly approaches the present shell, but a comparison of the two fossils, both of which are at Jermyn Street, points to their being distinct. The former is more swollen posteriorly, its anterior ear is much smaller, its rays are separated by much wider grooves,



which are finely striated, its umbo is more incurved, and its lunule longitudinally rayed. From *L. ovalis*, Desh., of Goldfuss, our shell differs in the nature of its markings and its larger ears.

A Yorkshire specimen of this shell bears the label "*Avicula multicostrata*, Bean." I have been unable to trace this name, which may be a manuscript one; but at all events, as Geinitz used the same name in 1842 for a Cretaceous shell, he very probably has the priority.

#### LIMA INCISA, Waagen.

1873. *Lima dustonensis*, Lyc. MSS., Sharp, Q. J. G. S. vol. xxix. p. 296.

1767. *L. incisa*, Waagen, Benecke's geogn.-pal. Beitr. p. 626.

In the Sharp Collection at the British Museum are two specimens of a large and rather convex *Lima* from Duston, which appears to agree with Waagen's shell, one of them bearing "Lycett's" upon its label. Being casts, it is not easy to form a definite opinion upon them; but there is in the same Museum a better-preserved specimen, stated to be from the "Great Oo." of Hardington, which seems very like the German shell both in shape and markings, the principal difference being that the broad flat rays and unpunctured grooves are only visible on the lateral portions of the fossil.

#### LIMA INOCERAMOIDES, n. sp., Eth. MSS. Plate XVII. fig. 5.

Shell large, very flat, only slightly oblique. Umbo subcentral. Posterior wing rather large. Lima-line short and low, but very steep; the surface in front of it being very concave. Margins forming a curve of almost equal convexity, the greatest curvature being in the middle of the inferior margin. The greatest depth near the centre of the valve at about one third the diameter from the umbo. Edges inclined to each other at a very small angle. Structure thin. Surface smooth and polished, with a few small indistinct growth-marks, and with five or six small and distant furrows on each side near the wings.

*Dimensions.* Length  $3\frac{1}{4}$  inches, breadth  $3\frac{1}{5}$  inches, depth  $1\frac{3}{4}$  inch.

There is a single specimen in the Jermyn-Street Museum, from the Inferior Oolite south of Perrott.

This is clearly a different species from the short-hinged *Plagiostoma laeve*, scantily described by Buckman in Murchison's 'Geology of Cheltenham,' p. 99. It approaches *Lima Etheridgii*, Wright, which is sometimes centrally smooth, but in that species the umbones are more median and the posterior wing larger. *Lima inquirenda*, Thurmann, Leth. Bruntr. t. 34. fig. 7, is a much more triangular shell; and *Lima plebeia*, Chap. & Dew., wider and more oblique. *Lima Hoperi* (Sow.) of the Chalk is its nearest analogue.

#### LIMA LÆVIUSCULA, Sow., var.

1822. *Plagiostoma læviuscula*, Sow. Min. Conch. t. 382.

1835. *Lima læviuscula*, Goldf. Petr. Germ. t. 102. fig. 3.

There is a fine specimen in the British Museum, from the Green Bed of Little Casterton, Northamptonshire, which is probably a variety of Sowerby's species. It is more convex than the generality of the Coral-Rag examples, its posterior wing is smaller and more defined, and its inferior margin somewhat straighter; so that it agrees rather better with the example figured by Goldfuss. The lineations become obsolete in the median portion of the valve.

#### LIMA LYCETTII, Laube?

1853. *Lima punctata*, Mor. & Lyc. Gt. Ool. Moll. pt. 2, t. 15. fig. 9.

1867. *L. Lycettii*, Laube, Bivalven von Balin, t. 1. fig. 12.

Some fine *Lima* occur in the Freestone of the *Murchisoni*-zone at Leekhampton. They are roundish convex shells, crowded with fine, multitudinous, and occasionally divaricating, smooth rays, divided by linear furrows containing coarse punctations, which sometimes become obsolete near the centre. The umbo is round and prominent, and the posterior ear is rayed and larger than the anterior one, which is half submerged in the lunule. The ornamentation is most distinct in the oldest shells.

Five specimens are in the Jermyn-Street Museum. I have one nearly 5 inches wide, and probably they reach a still larger size.

These shells have been generally referred to *Lima punctata*, Sow. Min. Conch. t. 113. figs. 1 & 2, but there can be no doubt that they do not belong to this Lower Liassic form\*. The rays are fewer, narrower, and do not divaricate. Moreover, he describes the shell as flatter, with nearly equal ears, and markings vanishing with age. On examining his figured specimens in the British Museum it is at once clear that it is a totally different shell; in fact his fossils seem to belong to two if not three species,—the largest almost smooth with lines of puncta, agreeing with Goldfuss's figure; the second with narrow ribs and striated furrows; and the last with shallow, smooth grooves. But however this may be, they are all very flat shells, and have no characters in common with the present species.

No doubt Morris and Lycett's shell belongs to this form; but it is by no means certain that Laube's does, as in his figure the concentric markings cross not only the furrows but the rays.

This Oolitic species is characterized by its numerous, smooth, and often divaricating rays, punctated grooves, and rounded shape.

#### LIMA MAJESTICA, n. sp. Plate XVII. figs. 6, 6a, 6b.

Shell very large, oblique, the shape of a semiellipse cut off by its shorter diameter, moderately convex, the deepest part being on the lima-line one third of its length from the umbo. Umbo very acute, narrow, moderately prominent, and truncated anteriorly. Lima-

\* The numbers of Sowerby's plates 113 & 114 are accidentally interchanged. Hence his figure of *L. rigida* is made to represent *L. punctata*. Joined to that description it may easily be interpreted as Morris and Lycett's shell, from which Sowerby's two species are really quite distinct; and this is probably the reason it has been misunderstood.

line  $\frac{5}{6}$  the length of the shell, which is truncated in front of it, and behind it spreads out flatly to the margins all round. Anterior ear very small, not extending beyond the perpendicular plane touching the lima-line. Margins forming a full and equally convex curve till they meet the end of the lima-line, where the edge curves suddenly in, and becomes slightly concave under the lima-line for about half its length, where it meets the depressed edge of the anterior ear. Growth-lines very numerous, indistinct, and lamellar. Rays about 50, those on the sides being very low flattened plaits with short steep sides, between broader flat grooves; and those on the central part merely broad, flat spaces, divided by narrow groove-lines. These two varieties of rays, however, often alternate, the broader flat ones seeming to split into two or three of the narrower steep ones.

*Dimensions.* 7 inches long, by  $5\frac{1}{2}$  inches wide, and 4 inches deep for the two valves.

There is one specimen from Rodborough in the Jermyn-Street Museum, another from the Lincolnshire Limestone of Stamford in the Sharp Collection of the British Museum, and a small one from Dinnington in the Bath Museum.

Mr. Lycett's specimen at Jermyn Street is labelled "*L. grandis*;" but this name cannot be used, as it has been already given by Römer to another species of the same genus.

In the Stamford specimen the rays are more numerous and narrower, especially upon and near the posterior wing; and the grooves have slanting sides, and form in section an almost regular undulation with the rays.

*Lima incisa*, Waagen, in Benecke's geogn.-pal. Beitr. vol. i. t. 30. fig. 3, differs from this shell by being much more convex. Its umbo is large, rounded, more prominent, and not anteriorly flattened, and extends beyond the margin of the posterior wing, which is small and posteriorly concave. Its margin is more swollen behind and less so in front, the furrows are deeper and angular, and the surface of the rays flat.

#### LIMA NOTATA, Goldf.

1835. *Lima notata*, Goldf. Petr. Germ. t. 102. fig. 1.

1849. *L. notata*, D'Orb. Prodr. sect. 13, no. 394.

1858. *Plagiostoma notatum*, Quenst. Jura, p. 627.

1867. *Lima complanata*, Laube, Bivalven von Balin, t. 1. fig. 11.

1871. *L. notata*, Terq. & Jour. Mém. Soc. Géol. Fr. ser. 2, vol. ix. p. 117.

There are six examples from the *Humphriesianus*-zone of Dundry in the Bristol Museum, three of which seem typical specimens; and I have several from Broadwindsor and the neighbourhood of Yeovil. They generally differ from the foreign figures in having the posterior ear strongly radiated. The species seems to vary considerably in length, obliquity, and the number of its rays. The punctations are usually clearly seen in the centre of the shell, but become obliterated near the margins.

Lycett quoted it in the 'Annals' from the Oolitic Marl and Great Oolite of Minchinhampton, but does not describe it in his Monograph published just afterwards. Hull, in the 'Geology of Cheltenham,' p. 34, gives it from the *Murchisoni*-zone of Cleeve Cloud. On the continent it extended as high as the White Jura.

LIMA PLACIDA, n. sp. Plate XVII. figs. 7, 7a.

Shell smooth, extremely wide and flat, very oblique. Umbo very small, acute, depressed, and flat. Anterior slope of lima-line convex, steep, with a very small narrow surface before it. Posterior ear well developed, high, and flattened. The inferior margins in a regular curve, which becomes shallower towards the front, so that the infero-anterior part is attenuated. Surface shining. Growth-lines numerous, but very fine, and chiefly distinguishable by white colour-bands. Rays numerous, but hardly visible, except in front, where they are marked by indistinct linear grooves; in other parts only separated by lines of coarse, distant puncta.

One specimen in the British Museum (Sharp Collection) from the Northampton Sand.

*Dimensions.* 15 lines long, 12 lines wide, and 2 lines deep.

This species is very well characterized, and I have met with no other species that approaches it. It is far the flattest *Lima* I have seen.

LIMA PLATYBOLUS, n. sp. Plate XVII. figs. 8, 8a, 8b.

Shell slightly convex, oblique, somewhat transverse, large. Umbo sharp and small, truncated in front by the long, steep, and elevated lima-line, which is three quarters the diameter of the shell in length; the shell being perpendicular in front of it, and behind it slightly convex, and then dilated flatly to the margins. Anterior ear very small, not extending beyond the perpendicular from the lima-line. Byssal sinus very large and ovate. Posterior ear rather large. Margins convex, the greatest curvature being on the posterior side. Valves meeting at a small angle. Surface covered by low flattened radiations, separated by simple grooves half the width of the plaits.

*Dimensions.* Length 31 lines, width 24 lines, depth 5 lines.

There are two specimens of this shell in the Jermyn-Street Museum, one from Nailsworth and one from Leckhampton.

This shell is similar to *Lima tumida*, Röm., in its markings, but is very much flatter and of a different shape. From *Lima notata*, Goldfuss, it is distinguished by its more incurved and truncated umbo, its greater convexity, its larger posterior and smaller anterior wing, and its smooth unbarred grooves.

LIMA PLEBEIA, Chap. & Dew.

1853. *Lima plebeia*, Chap. & Dew. Terr. Sec. de Lux. t. 28. f. 1.

There are fine specimens, identified as this shell by Mr. Tawney, in the Bristol Museum. They are from the Iron-shot Oolite of Dundry, from which I have myself obtained it.

A fragment of another species from Dundry appears rather similar



to *Lima aequilatera*, Buv. Meuse, t. 18. fig. 14, but is insufficient for identification.

*LIMA POETICA*, n. sp. Plate XVII. fig. 9.

Shell convex, transverse, slightly oblique, almost circular, with prominent, distant, and rather pointed incurved umbones, which project about the fifth of an inch beyond the hinge-line, and are slightly posterior. Ribs about 20, sharply pointed and triangular in section, separated by flat interspaces of a similar width, so that a section would give a number of low triangles arranged their own breadth apart. Slight furrows running down the centre of each interspace, and faint traces of other radiations. The whole surface crossed by numerous, coarse, and exceedingly regular, flounce-like lines of growth, which become serrations on the top of the ribs. Wings equal, unribbed, and continuous with the rest of the shell. Hinge-line 8 lines in length.

*Locality.* Dundry. One specimen in the Bristol Museum and one in my own collection.

*Dimensions* of one valve 15 lines in length, 14 lines in breadth, and 5 lines deep.

This shell appears to be very distinct. In shape and general form it slightly resembles *L. gibbosa*, Sow., but is much less elongate, and the markings are totally different. *Lima acuticosta*, Quenst. Jura, t. 18. fig. 22, is much smaller and longer, and has more defined ears; while the small *Avicula clathrata*, Lyc. Suppt. t. 40. fig. 7, which much resembles it in ornamentation, is much wider near the hinge, flatter, and less oblique.

*LIMA RODBURGENSIS*, Lyc. MSS. Plate XVII. fig. 10.

1873. *Lima rodburgensis*, Lyc. MSS. Sharp, Q. J. G. S. vol. xxix. p. 291.

Shell convex, not very oblique. Umbo very large, rounded, and prominent. Lima-line slightly concave,  $\frac{1}{5}$  of the length of shell in that direction. Greatest convexity of the valve at  $\frac{1}{5}$  of the diameter behind the lima-line. Surface sloping straight up from the margins, and curving over this point down to the lima-line, which is at a much lower level, and then sweeping round with a great concavity, so as to form a very large and deep lunule. Anterior wing small, hidden within the lunule, margin starting from it concave, but becoming exceedingly convex round base of lima-line, then proceeding at about the curvature of a circle to the posterior side, where it again curves very rapidly before reaching the posterior wing. Surface with whitish growth-lines, the most prominent dividing the shell into three parts, and very numerous, obscure, flat rays, separated by indistinct, smooth, linear furrows, chiefly seen at the sides.

*Dimensions.* Length 20 lines, width 15 lines, depth of each valve 5 lines.

One specimen in the Sharp Collection in the British Museum from Northamptonshire.

This species approaches *Lima strigillata*, Laube, but is a more

convex and less oblique shell. Its lower margin forms a semicircle, curving more strongly at each extremity. Compared with *L. glabra*, Münst., Goldf. Petr. Germ. t. 102. fig. 9, it is much shorter and less trigonal.

*LIMA SEMICIRCULARIS*, Goldf.

1833. *Lima semicircularis*, Goldf. Petr. Germ. t. 101. fig. 6.

1853. *L. semicircularis*, Chapuis & Dew. Foss. de Lux. t. 30. fig. 5.

1857. *Lima semicircularis*, Oppel, Jura, p. 415.

1858. *Plagiostoma semicirculare*, Quenst. Jura, t. 59. fig. 11.

There are specimens of this shell from the *Parkinsoni*-zone of Rodborough at Jermyn Street, and from the *Humphriesianus*-zone of Dundry in the Bristol Museum; and I have obtained it from the *Parkinsoni*-zone of Bradford Abbas. The fine valve from Rodborough measures  $2\frac{3}{4}$  inches long, by  $3\frac{1}{2}$  wide, and  $\frac{3}{4}$  deep. The specimens seem to agree exactly with the German shell, and to differ from *L. notata*, Goldf., by their much finer radiations.

The shell figured under this name by Morris and Lycett in their Monograph (pt. 2, t. 3. fig. 3), of which the types are also at Jermyn Street, does not belong to the same species. It has much larger and fewer ribs, and a more diffuse posterior ear, and appears to be the same as *Lima virdunensis*, of Buvignier, Statist. Géol. de la Meuse, t. 18. fig. 30. I am not aware that it is even found in the Inferior Oolite.

*LIMA SEMINUDA*, n. sp. Plate XVII. figs. 11, 11 a.

Shell transversely convex, very attenuated in front, dilated in the postero-inferior region, flattened posteriorly. Umbo incurved, acute, distant, facing forwards. Anterior wing small, hardly projecting beyond the lunule; posterior wing rather large and confluent. Lunule large, scarcely concave. Lima-line almost the same length as the shell. Surface smooth, except the lunule and the part over the lima-line, which are covered by nine raised distant ridges with smooth interspaces.

*Dimensions.* Length 17 lines, width 11 lines, depth of one valve 3 lines.

There is one specimen of this shell from Nailsworth in the Jermyn-Street Museum.

This species is very distinct both in its shape and in the sudden cessation of its decoration. The surface is very much arched over the whole length of lima-line, and thence spreads out almost flatly to the lower and hind margins.

*LIMA SHARPII*, n. sp. Plate XVII. figs. 12, 12 a.

Shell flatly ovoid. Lima-line short. Umbo sharp and small. Ears not compressed, well developed, and equal. Anterior ear rugged, spreading well out beyond lima-line. Surface dilate behind. Ribs about 40, distinct over all the surface, with low and rather flattened tops, distant, simple, and somewhat undulating, with shallow, smooth, flat furrows, which are decidedly wider than the

ribs. Surface broken by occasional prominent growth-lines, which become more numerous near the margins, where small, indistinct, subsidiary ribs start in the centre of furrows.

*Dimensions.*  $4\frac{1}{2}$  inches long, by  $5\frac{1}{2}$  wide, and  $2\frac{1}{2}$  deep for both valves.

One specimen in the British Museum, from Brockhall, Northamptonshire.

This shell approaches *Lima majestica* in size and shape, but is less compressed or pinched, and longer; its ears are not so compressed, the surface is more regularly convex, and the lima-line more rounded, much less prominent, and shorter, so that the greatest depth is at a point one quarter of its diameter in rear of it. The plaits are also very different, being fewer and higher, with broad, flat, smooth interspaces, and becoming much more crowded on the posterior ear. The growth-lines are lamellar, becoming near the margins irregularly crowded and foliaceous.

#### LIMA STRIGILLATA, Laube.

1853. *Lima bellula*, Morris and Lycett, Gt. Ool. Moll. pt. 2, t. 3. fig. 9.

1867. *Lima strigillata*, Laube, Bivalven von Balin, t. 1. fig. 4.

1871. *Lima bellula*, Terq. and Jourdy, Mém. Soc. Géol. France, ser. 2, vol. xix. p. 117.

This shell appears to be very common in the Lower Oolites. Lycett, in his 'Cotteswold Hills,' quotes it from the Upper Lias Sands, the Gryphite Grit, and the Trigonion-Grit, as well as from the Great Oolite of Minchinhampton. Sharp also gives it from the Lincolnshire Limestone and the Northampton Sand. The specimens which I have collected from Dundry, Cleeve Cloud, &c., seem to approach Laube's figure much more nearly than the Great-Oolite specimens, which are more angulated and depressed anteriorly, as well as smooth. Morris and Lycett, however, state that the smoothness increases with age. In 1850 D'Orbigny, in his 'Prodrome,' Sect. 13. No. 395, had given the name *L. bellula* to a distinct twelve-ribbed species; and as he has priority, Laube has changed Lycett's name. The shell appears to be very like *Lima gigantea*, Sow.

Terquem and Jourdy's figure of an aged shell show well-marked rays, though both they and Morris and Lycett describe it as becoming smooth when adult.

#### SPONDYLUS NIDULANS, E. Desl.

1858. *Spondylus nidulans*, E. Deslongchamps, Mém. Soc. Linn. Norm. vol. xi. t. 20. fig. 5.

I have an imperfect shell from the *Humphriesianus*-zone of Dundry, which appears to belong to this species; and there is another in the British Museum from the Inferior Oolite of Stroud.

#### HARPAX PARKINSONI, Quenst. sp.? Plate XV. fig. 20.

1818. *Plicatula spinosa*, Sow. Min. Conch. t. 245 (description only)?

1852. *Plicatula Parkinsoni*, Quenst. Handb. t. 41. fig. 24.

1858. *Harpax spinosus*, Deslongchamps, Mém. Soc. Linn. Norm. vol. xi. t. 10. figs. 26-37.

I have found specimens which apparently agree with Deslongchamps's shell, t. 10. fig. 33, in the beds below the sands belonging to the *Jurensis*-zone at Yeovil Junction.

He states that these shells, which are from the Inferior Oolite of Calvados, do not agree with the one described by Sowerby, which he considers to be a different species from his figure, and which he calls *H. Parkinsoni*.

As, however, Sowerby's name *P. spinosa* is generally accepted for the common Middle-Lias fossil, there would seem to be no reason for the alteration proposed by Deslongchamps, even had not Quenstedt already given the former name to the present species on account of its occurring in the *Parkinsoni*-beds of Germany.

I have seen several specimens of the true *H. spinosus* (Sow.) which were said to be from the Inferior Oolite of Half-way House, but on examining them I found reason to believe that they really came from the Middle Lias of the same district.

*HARPAX TAWNEYI*, n. sp. Plate XV. figs. 18, 19.

The specimens of this species are all interiors of the left or free valve. Shell irregularly oblate or ovoid, concave interiorly, the flattish central half being surrounded by a prominent, obtuse, uneven ridge, or pallial line; outside which, the surface slopes steeply down to the margins, and is covered by indications of 30 or 40 coarse, short, and very irregular ribs; muscle-mark large, circular, subcentral and granulated; hinge well displayed, and consisting of two nearly parallel ridges on each side, meeting each other at a high angle, and enclosing a shallow groove; shell-structure thin and opalescent.

*Locality.* The Ironshot Oolite of Dundry. There are three fine specimens in the Bristol Museum, and one or two in my own collection. The latter I obtained from the quarry near the cross roads.

*Dimensions.*  $1\frac{3}{4}$  inch long, by 2 inches broad, and 3 lines deep; or  $1\frac{3}{4}$  inch long, by  $1\frac{1}{2}$  broad, and 4 lines deep.

Although the exterior is unseen in any of the specimens, it may be presumed from the characters shown in the interior, that it was ribbed or spined. It is unlike any of the "*Plicatules*" described by Deslongchamps in the 'Memoirs of the Linnean Society of Normandy,' 1858; for though it bears some resemblance to *Plicatula pectinula*, Desl. loc. cit. t. 17. fig. 38, it is easily separable from that shell by its larger size, less smoothness, and the characters of its hinge.

*PLICATULA FISTULOSA*, Morr. and Lyc.

1853. *Plicatula fistulosa*, Morris and Lycett, Gt. Ool. Moll. pt. 2. t. 2. fig. 5.

1871. *Pl. fistulosa*, Terq. and Jourdy, Mém. Geol. Soc. Fr. Sér. 2. vol. 19, p. 131.



There is a specimen of this Gt. Oolite shell in the Bristol Museum from the Inferior Oolite of Bradford Abbas, and one in the Jermyn-Street Museum from the Gryphite Grit of Leekhampton. I have one from the same locality.

*PLICATULA SOLLASII*, n. sp. Plate XV. figs. 21, 21 *a*, 22, 22 *a*, & 22 *b*.

Shell small, equilateral, transversely subtriangular or lozenge-shaped, depressed, adhering by the greater part of the right valve, and then suddenly rising perpendicularly, to form a rim of more than a line in height, below which the adhering surface is slightly expanded; umbo indistinct and small; margins starting from it at a slight slope, curving suddenly at the shoulders (which are the widest part of the shell), and then running down obliquely in almost straight lines, till they meet at the centre of the lower part in a strong curve; interior with fine reticulations on the flat part, formed by rounded curving lines, which branch so as to form lozenge-shaped spaces. Similar, but closer markings, broken by one or two transverse ridges, are continued on the inner surface of the rim; the exterior surface of which is covered by numerous, indistinct, elongate striae.

Left valve (fig. 22) with the interior slightly concave, and then sinking perpendicularly to form a marginal rim two lines deep; concave part with indications of markings similar to those of the other valve but much larger. On the curve of the rim are numerous elongate serrations, the perpendicular side of the rim being smooth, and the edge covered by fine crenulations. The exterior of this valve is entirely hidden by the matrix.

*Locality.* Dundry.

*Dimensions.* 5 lines long, 6 wide, and 1 deep.

I have collected many specimens of the right valve adhering to a flat surface of stone, which was bored by Annelids and *Lithodomi*. They appear very uniform in shape. I found a single left valve in the upper part of the *Humphriesianus*-zone in the same quarry; and, though there are some differences in markings, there seems to be no reason to suppose that it belongs to a different species. This shell comes very near *Pl. reticulata* of Deslongchamps (*loc. cit.* t. 18. fig. 24-35), but seems to differ in shape, and the presence of markings on each surface of the rim in the right valve. *Pl. lepis* of the same author is a more elongated and rounded shell, and is smooth on the interior of the rim.

*Spondylus dichotomus*, Buv., differs in being orbicular as well as in the absence of marking on the inner surface of the rim.

*PLICATULA SUBSERRATA*, Goldf., sp. Plate XVI. figs. 4, 5.

1834. *Ostrea subserrata*, Goldf. Petr. Germ. t. 74. fig. 1.

1852. *Plicatula impressa*, Quenst. Handb. t. 41. fig. 27.

1857. *Plicatula impressa*, Oppel, Juraf. Sect. 80, no. 90.

1858. *Plicatula subserrata impressa*, Quenst. Jura, t. 73. fig. 45, 46.

Small shells which appear to agree with this species occur in

the Inferior Oolite of Bradford Abbas. The right valve is marginally convex, but centrally flat; the umbo, which was probably gone in Goldfuss's specimens, is small, delicate, and bent backwards. It is covered by about 15 sharp distant rays, which have a tendency to become spinulose. The left valve is flat or concave, covered by innumerable granulations which tend to arrange themselves in longitudinal lines.

It seems to occur in Germany higher in the series. D'Orbigny has given Goldfuss's name as a synonym for *O. gregaria*, but apparently without reason. It bears some resemblance to *Pl. catinus*, Desl., Mém. Soc. Linn. Norm. vol. ii. t. 16. fig. 8; but in that the rays are less acute, and the upper valve is smooth.

*GERVILLIA GLADIOLUS*, n. sp. Plate XVI. figs. 7, 7a.

Shell very straight, sabre-shaped and elongated, exceedingly oblique, nearly equivalve, convex near umbo, but almost flat in the further half of the shell; edges acute; hinge-line apparently less than half the length ( $2 : 2\frac{1}{2}$ ): umbones at the anterior extremity, small, approximate, and not distinct from the rest of the surface, that of the right valve being much the smaller; the margins nearly parallel, the anterior one curving suddenly round to the umbo, so that the anterior auricle must be rudimentary; shell exceedingly thin, apparently crowded with fine, concentric, irregular striæ, which appear somewhat pustulose; posterior muscle-mark in the centre of the shell, large, ovoid, and concentrically ridged.

*Locality.* Dundry. One specimen in the Bristol Museum.

*Dimensions.* Length  $1\frac{1}{2}$  inch, breadth  $5\frac{1}{2}$ , depth  $\frac{2}{3}$ .

This fine shell seems to be very distinct. I have found nothing at all approaching it described from Jurassic rocks. The fossil is, in parts, much worn so as to give the interior characters, but in other parts the original surface seems to remain uninjured. The matrix is deep-yellow ferruginous sand including numerous rounded quartz grains, a not unusual condition in the Dundry beds.

*GERVILLIA INTERMEDIA*, n. sp. Plate XVI. figs. 8, 9.

Shell extremely inequivalve, somewhat contorted; right valve elongated, very convex, especially longitudinally, subspirally curved to umbo, which is very prominent and carries on the same curve over the hinge-line, almost at its anterior point; anterior auricle distinct, but small; hinge-line twisted in front, elongated, two thirds the width of the shell; anterior margin very steeply curved. Margins inclining to each other at a slight angle, and meeting in a very convex curve at the postero-inferior corner; posterior margin slightly concave near the hinge-line. Surface in most specimens covered with slight irregular growth-lines, but, in one very well-preserved specimen, showing very numerous, concavely scalloped, delicate, concentric laminae, of which some traces may be seen in the other specimens.

Left valve very much smaller, longitudinally flat, transversely convex; umbo small, not reaching hinge-line; very differently

marked from the other, being covered with very numerous, simple, parallel, regular laminae.

*Locality.* There are three specimens from Dundry in the Bristol Museum, and I have obtained it from that place as well as from Bradford Abbas, and from the Sands of Frocester. Other specimens are at Jermyn Street.

*Dimensions* of both valves  $1\frac{2}{3}$  inch long,  $3\frac{2}{3}$  wide, and 1 inch deep.

Though it seems to be a not uncommon shell, I have been unable to identify it with any species of which I have seen a description. *G. laevigata* is too indistinctly described by Lycett in the Annals of Nat. Hist. 1850 to be recognizable. Mr. Tawney has conjecturally named the species *G. tortuosa*; but it seems to me very distinct from the specimens of that shell which I have seen, as well as from Sowerby's figure. Phillips's figure of *Gastrochena tortuosa*, though nearer to it, is still much shorter and more oblique. Quenstedt's figure of the smaller valve of the same species (Jura, t. 48. fig. 19) is rather like, but more oblique and very different in ornamentation. *G. radians*, Morr. and Lyc., has a much larger umbo, and is more contorted and less oblique. *G. lata*, Phill., Geol. Yorksh. vol. i. t. 11. fig. 16, and *G. Hartmanni*, Münst., Goldf. Petr. Germ. t. 115. fig. 7, are much more equivalent shells. It may possibly agree with *G. fornicata*, Lycett, 'Cotteswold Hills,' p. 121, but seems to differ in wanting the sinuations in the infero-anterior border, and being less oblique.

GERVILLIA COMPRESSA, n. sp. Plate XVI. fig. 6.

Shell flattish, very oblique, moderately transverse; umbo very anterior, not prominent, facing and sloping forward, acute, and not rising above the level of the hinge-line; front auricle small and convex; hind auricle large and very flat or even concave. Hinge-line straight and nearly of the same length as the shell. The margin of front auricle convex, and then, after a short sharp concavity, where it meets the body, continuing in a curve, almost that of an egg, nearly from its acute to its obtuse end. It then curves more suddenly, and from this point a line runs up, at first slightly concave, and then convex, in rear of and defining the umbo; the posterior edge, after coinciding with this line for about one sixth of its length, proceeds for some time obliquely from it, and then becomes decidedly concave as it turns out to meet the posterior end of the hinge-line. Surface smooth, with a few indistinct growth-striae: in front of the above-mentioned line, it suddenly rises, and then becomes flatly convex, being spathulate in its infero-posterior part. It slightly overlaps the general margin at the antero-inferior corner.

There is a single left valve from Nailsworth in the Jermyn-Street Museum, which measures 18 lines long, 28 wide, and 10 deep.

The most marked features are its obliquity, the sharp line behind the umbo, and its very slight convexity; thus it approaches *Pteroperna plana*, Morr. and Lyc., though it is very different from that species.

It is rather similar to *Avicula modiolaris*, Goldf. Petr. Germ. t. 118. fig. 5, but is a much flatter and more oblique shell.

**PINNA CLAVIFORMIS, n. sp.** Plate XVI. fig. 11.

Shell large, club-shaped, subangulate in front, flattened and much expanded behind; apex produced; dorsal side very concave; antero-inferior side long and straight; postero-inferior side curved; postero-inferior corner convex; surface with no signs of radiations, but with rather regular curved, concentric bands, formed by distinct bulges of growth, which are covered by indistinct thread-like concentric striæ, are oblique and most prominent in the central part of the valve, and curve suddenly forward, to unite with the margin. There is one specimen in the Jermyn-Street Museum.

*Dimensions.* 5 inches long, by 9 wide, and 2 deep.

It appears to be a more curved and inequilateral shell than *Pinna ampla* (Sow.), and also wants the longitudinal markings, which, however, Morris and Lycett state to be sometimes absent in the latter shell. Thurmman and Etallon, Leth. Bruntr. t. 28. fig. 3, give a figure of *P. ampla* which approaches it a little more nearly in shape, though still remaining distinct.

**PINNA DUNDRIENSIS, n. sp.** Plate XVI. fig. 10.

Shell large, hastate, flattened, very oblique; anteriorly convex and subacuminate; dorsal side straight: inferior side rather swollen posteriorly; surface with 12 or 13 distinct, radiating straight lines, one of the central ones being larger than the others, which are distant and very rounded, and are rendered nodulous on the lower half of the surface by very distant indistinct transverse lines. Test of two layers, the outer of which is about the eighth of an inch thick, and perpendicularly fibrous.

*Dimensions.* 3 inches by 5 inches, and  $\frac{3}{4}$  inch deep.

I have found this shell at Dundry in the *Humphriesianus*-zone, but generally in fragments. There are specimens from that place in the Bristol Museum, and from the Inferior Oolite of Litchborough and Dundry in the British Museum.

It appears to be a much flatter, broader shell than *P. cuneata*, Bean, and has fewer rays and less convexity than *P. fissa*, Goldf. *P. ampla*, Young and Bird, appears to be of quite a different shape.

**MYTILUS PRIMIPILARIS, n. sp.** Plate XVI. figs. 13, 13a.

Shell oblique, hastate, somewhat convex in front, very much flattened and produced at the supero-posterior corner; umbo quite anterior, small and pointed, projecting forward and slightly compressed at its extremity; hinge-line very long, slightly convex, more than  $\frac{3}{4}$  the width of the shell; anterior wing very small and distinct; inferior margin very oblique and straight; infero-posterior corner rounded; posterior side oblique, forming an obtuse angle with hinge-line; surface with a few steep, smooth, step-like lines of growth at unequal distances, the lines of greatest convexity running near and parallel to the antero-inferior border.

*Dimensions.* 16 lines long, 8 wide and 6 deep for both valves.

In the Jermyn-Street Museum there are three specimens from the



Inferior Oolite of Stubbington, and in the British Museum one from the Barnack Rag.

It is quite unlike *Mytilus lunularis*, Lycett, 'Cotteswold Hills,' p. 128, which has a sharp concave ridge overhanging the whole anterior side to the inferior margin: neither do I think it agrees with *Mytilus Leckenbyi*, Morr. and Lyc., pt. ii. t. 14. fig. 9, on account of its larger anterior wing and more angulated posterior margin, or with *Mytilus Binfieldi*, Morr. and Lyc., pt. ii. t. 4. fig. 10, on account of the more twisted nature of its surface. *M. sublævis*, Sow., as figured by Morris and Lycett, pt. ii. t. 4. fig. 19, is more arched in front and flatter behind, and *M. unguatus*, Young and Bird = *M. tumidus*, Morr. and Lyc., loc. cit. fig. 6, is more tumid, and has a larger anterior wing.

**MYTILUS STRIATISSIMUS**, n. sp. Plate XVI. fig. 12.

Shell elongated, oblique, arched or laterally unguate, sometimes rather squared behind; very convex in front, but flattened towards the inferior margin. Umbones terminal, acute, elongated, and curved forward, depressed and attenuated at the apex. Lines of growth distant and well marked, becoming closer and sharp near the margins. Radiations very fine and extremely numerous, close, rounded, and smooth, except that they are rendered somewhat rugose or zigzag by the crossing of the lines of growth, but not ornamented by transverse markings, very regularly radiating and, occasionally, dichotomizing, so as to remain the same size on all parts of the shell. Anterior ear very small and steep, having a small portion of the surface smooth and without rays on its hinder part. Hinge-line straight and of considerable length. Anterior margin concave; posterior convex; inferior ovate.

*Dimensions.*  $2\frac{1}{4}$  inches long by  $1\frac{1}{2}$  wide by  $2\frac{1}{2}$  deep for both valves (Bristol Museum).

There are two specimens in the Bristol Museum from Dundry; two in the British Museum labelled "Leckhampton" (though having much the appearance of Dundry fossils), and a smaller one in the Jermyn-Street Museum from Castle Cary, near Bruton.

This shell is distinct from *Mytilus furcatus*, as figured by Goldfuss, by Quenstedt, and by Morris and Lycett. In all of these the ribs are much larger, fewer, and highly ornamented.

*Modiola aspera*, Sow., differs by having imbricated and fewer ribs, and a much more elongated anterior wing. It is still more unlike Phillips's figure of this shell, which Lycett supposes to represent *M. furcatus*, and which D'Orbigny has referred to a distinct species under the dreadful name of "*subasperus*."

It more nearly approaches *Mytilus pectinatus*, Sow., Min. Conch. t. 282; but in this Corallian fossil, the rays seem to be very much finer, and the anterior wing still smaller and without any smooth surface; while it is a much straighter and more wedge-like shell. This was quoted by Lycett, in the 'Annals,' 1850, from the Inferior Oolite and Great Oolite of Gloucestershire; but it is not mentioned in his monograph, which was published soon afterwards.

*Mytilus gradatus*, Terq. & Jourd., is squarer in shape, with more broken radiations.

*ARCA ÆQUATA*, n. sp.

Shell very transverse, attenuated behind, smooth, excepting indistinct lines of growth. Umbo nearly central, depressed along its centre, elevated, incurved, rather slender, distant, but not extremely so, very slightly facing forwards. A prominent subacute angle runs down from the posterior side of the apex to the infero-posterior corner of the shell, the posterior wing which is defined by this being very concave. Hinge-line somewhat concave by its extremities being raised; anterior and posterior sides inclined obliquely to it, and parallel to each other. Inferior margin slightly concave in the middle.

*Locality.* Leckhampton. There is a specimen in the British Museum from the freestone of the *Murchisoni*-beds of that hill.

*Dimensions.* 6 lines long, 14 wide, and 3 deep for the single valve.

The keeled and central beak joined to the great width distinguish this shell.

It is much like *Cucullæa ferruginea*, Lycett, 'Cotteswold Hills,' p. 125, in general shape, but differs from that species in being smooth.

*ARCA CULMOTECTA*, n. sp. Plate XVIII. figs. 1, 1a.

Shell very transverse, quadrately ovoid, moderately convex. Umbones very small, moderately distant, anterior (situate about one third of the width from the anterior side), facing forward, much flattened, so that the back of the shell is flattened and bounded by two rather sudden convexities as it sinks to the wings. Hinge-line about two thirds the width of the shell, with numerous oblique teeth on each side, those in front being the closest. The corners of the hinge-line somewhat rounded, especially the rear one, the side margins meeting them obtusely. The anterior margin nearly evenly convex, the inferior margin nearly straight, but curving very suddenly round its posterior corner, after which the margin goes obliquely to the hinge-line.

Surface covered by small, close, rounded, smooth rays, occasionally dichotomizing; growth-lines distant, more or less distinct, in some specimens hardly breaking the rays.

Two specimens from Dundry, in the Bristol Museum, and two (one from Dundry and one from Cold Comfort, near Cheltenham) in the British Museum.

*Dimensions* of each valve, 11 lines long by 23 wide, and 4 deep.

This shell seems to be distinguishable by its very small and proximate umbo, and by its crowded even rays.

*Arca ovata*, Buckm., in Murchison's 'Geology of Cheltenham,' bears some slight resemblance to this shell; but it would appear to be distinct on account of the more central and pointed umbo, and the much more distant striae. Buckman's name, moreover, appears to have been before used by Gmelin, as well as by Sowerby in

Murchison's 'Siluria,' for a Devonian shell, the latter, however, probably not being now referable to the same genus.

*MACRODON?* *RAPIDUS*, n. sp. Plate XVIII. figs. 2, 2 a, 3.

Shell very transverse, flat and ovate. Umbo very anterior, small, depressed, proximate, and slightly curving forward. Surface much flattened on the back, decidedly concave behind the rounded line from the umbo to the posterior point, and indistinctly so at the supero-anterior corner; covered by very numerous, low, rounded rays, which are frilled by multitudinous transverse markings, are separated by channels of their own width, and become gradually larger towards the posterior angle. A few impressed lines of growth. Anterior margin very convex, and posterior one extremely so, the greatest curvature in both being in the inferior part. Inferior margin slightly convex. Hinge-line much less than the transverse diameter, bluntly subangular in front, curved behind, very narrow, marked by three or four long, curved, transverse lines, with four very small oblique teeth at each extremity.

*Dimensions.* Length 16 lines, width 36 lines, depth 5 lines (for one valve).

There is a very fine specimen in the Jermyn-Street Museum, and a less perfect one in the Bristol Museum, both from the *Humphriesianus*-zone of Dundry. In the former, no signs of the teeth could be found, and this threw great doubt on its genus, until the hinge was developed in the Bristol specimen. If, as is probable, the long transverse lines belong to the ligamental area, then the hinge itself would be almost linear for the greatest portion of its width.

*MACRODON* *RASILIS*, n. sp.

Shell extremely transverse, oblique, very convex. Umbones moderately elevated, much incurved but very distant, very anterior and facing forward. Hinge-area broad and somewhat excavate. Hinge-line long, with several radiating teeth in front, and one long and two short transverse ones behind; extremities angular. Anterior margin oblique, convex; inferior straight; and posterior deeply convex. Valves slightly concave immediately below the posterior end of the hinge-line, otherwise roundly convex; slightly depressed and gaping at the centre of the inferior side. Surface smooth, excepting numerous irregular growth-lines.

*Dimensions* of each valve, 5 lines long, 15 lines wide, and 3 lines deep.

*Locality.* Bradford Abbas; one specimen in the Bristol Museum.

This specimen is very similar to *Cucullæa elongata*, Sow., Min. Conch. t. 447. fig. 1, in general shape, but differs in the absence of radiations. From *Arca sublata*, D'Orb., which is figured by Thurmann and Etallon, Leth. Bruntr. t. 26. fig. 8, and is the *Arca lata* of Koch and Dunker, Verst. nordd. Oolgeb. t. 7. fig. 10, it is distinguished by its greater width, rounder form, and more anterior and less pointed umbo. *Arca elongata*, Goldf. t. 123. fig. 9, is a more angular and radiated shell, and is considered to be the young form of *Macrodon hirsonensis*, D'Arch.

*NUCULA ÆQUILATERALIS*, Terq. & Jourd. ?

1858. *Nucula*, sp., Quenst. Jura, t. 73. fig. 52.

1871. *N. æquilateralis*, Terq. & Jourd. Mém. Soc. Géol. Fr. ser. 2, vol. ix. t. 11. f. 23-25.

I have collected some minute shells from the *Humphriesianus*-zone of Bradford Abbas, which have a close resemblance to this shell, but are rather less transverse and equilateral, so that a distinct escutcheon may be observed. From the Liassic *Nucula palmæ*, Quenst. Handb. t. 44. fig. 8, and Jura, t. 13. f. 42, they differ by having a much smaller umbo and being a more perfect oval. As they are all closed valves, I am not at all certain that they even belong to this genus, in spite of their general resemblance to Terquem's shell.

*NUCULA SUBGLOBOSA*, Römer. Plate XVIII. fig. 4.

1836. *Nucula subglobosa*, Röm. Ool. Geb. t. 6. fig. 7.

1837. *N. nucleus*, Deslongchamps, Mém. Linn. Soc. Norm. 1837, t. 1. fig. 8.

1849. *N. subglobosa*, D'Orb., Prodr. sect. 9, no. 209.

1849. *N. nucleus*, D'Orb., Prodr. sect. 10, no. 344.

1853. *N. subglobosa*, Chap. & Dew., Foss. Lux. t. 24. fig. 8.

1858. *N. Hammeri*, Quenst. Jura, t. 43. fig. 7, 8.

1869. *N. subglobosa*, Brauns, Mittl. Jura, t. 261.

Shell exceedingly convex, ovoid, truncated in front, rather sharply convex behind. Umbo anterior, proximate. Surface, with irregular impressed growth-striæ. Lunulæ distinct. Inferior margin curved. Structure massive. Hinge large, curved, covered with numerous parallel teeth.

The closed shell measures 5 lines long by 6 wide and  $4\frac{1}{2}$  deep. It is common in the rubbly beds of the *Humphriesianus*-zone at Bradford Abbas. There are also numerous examples of it in the Jermyn-Street Museum from various localities.

This species is undoubtedly the *N. nucleus*, Desl., from the Inferior Oolite of Calvados, with which it has been identified by the Jermyn-Street authorities; but I am unable to see any difference between it and *N. subglobosa*, Röm., or Quenstedt's rounder variety of *N. Hammeri*. His wider variety, which agrees with Goldfuss's t. 125. fig. 1, and is probably the same as *N. Hammeri*, Deufr., as argued by Quenstedt, p. 313, against D'Orbigny, occurs rather higher in the English Jurassic series.

*N. subglobosa* is given by Morris and Lycett as a synonym of *N. variabilis* (Sow.), from which the present shell is certainly distinct; but while upon comparison Römer's species seems decidedly separate from that figured in the monograph, it does not appear distinguishable from these Dorsetshire fossils, which vary considerably, and are often wider than the specimen figured in the accompanying plate. I therefore feel obliged to retain Römer's name in preference to that of Deslongchamps.



*NUCULA NUCIFORMIS*, n. sp. Plate XVIII. figs. 5, 5a.

Shell small, nearly spherical, oblique, very convex. Umbones extremely large, anterior, but curving round regularly, and becoming proximate and subacute at their extremities. Lunule bounded by a rounded circular groove, within which the surface swells again, so that the anterior side, the lunule, and the side of the umbo are in one flat plane. Posterior and inferior margins meeting in a somewhat produced rounded corner, the ventral margins of the two valves meeting perpendicularly. Surface with irregular growth-lines, and four or five much deeper depressions, so that it appears concentrically swollen in three or four curves.

*Locality.* Dundry. One specimen in the Bristol Museum.

*Dimensions* of both valves, 6 lines long by 5 wide, and 5 deep.

This may possibly be only an extreme variety of the preceding form, although its prominent lunule and spherical shape seem to individualize it very strongly.

*ISOARCA CAPITALIS*, n. sp. Plate XVIII. fig. 6.

Shell massive, very convex, and transverse. Umbo extremely swollen, incurved, and rounded, situated at one fourth the diameter from the anterior side, and nearly proximate. Hinge rather less than the width of the shell, bluntly angular in front, and covered with very numerous oblique teeth, which are longest on the anterior side. Hinge-area very narrow, bounded behind by a strong ligamental ridge, which curves from the umbo to the posterior end of the hinge. Side margins obliquely divergent; antero-inferior corner moderately, and postero-inferior corner exceedingly convex; inferior side nearly straight. Surface very convex, except at the superior corners, covered by occasional strong growth-ridges, and by multitudinous microscopical close flat rays.

*Size of each Valve.*—Length  $1\frac{1}{2}$  inch, width  $2\frac{1}{2}$  inches, depth 1 inch,

This shell, of which there are four specimens at Jermyn Street, from the *Parkinsoni*-zone of Rodborough, is very similar to *Isoarca transversa*, Quenst. Jura, t. 78. fig. 9, which, however, is less transverse, more rounded in front, and has a more anterior umbo. *I. ovata*, Laube, 'Bivalven von Balin,' t. 3. fig. 1, still more nearly approaches it; but its posterior margin is much more evenly rounded, and the teeth are smaller in the front part of its hinge.

*ISOCARCA TEXATA*, Münster., sp. Plate XVIII. figs. 7, 7a.

1832. *Isocardia cordiformis*, Zieten, Verst. Württ. 62. fig. 3.

1832. *Arca obliquata*, Zieten, Verst. Württ. t. 70. fig. 2.

1836. *Pectunculus texatus*, Münster., Goldf. Petr. Germ. t. 126. fig. 1.

1836. *Isocardia texata*, Münster., Goldf. Petr. Germ. t. 140. fig. 1.

1843. *Isoarca texata*, Münster. Beitr. z. Petr. vi. 83, t. 4. fig. 18.

1858. *I. texata*, Quenst. Jura, t. 78. fig. 11.

1858. *Isoarca cordiformis*, Quenst. Jura, t. 93. fig. 17.

A shell from Nailsworth, in the Jermyn-Street Museum, is almost

exactly like the smaller of the two shown in Quenstedt's figure on his t. 93. It is perhaps slightly more transverse. It would almost seem as if two distinct shells were united in the above synonymy, the other one being an ovoid shell much like *I. transversa*, Müntst.; but the material at hand does not appear sufficient for settling the point. The English shell is beautifully marked with fine close-beaded rays.

#### LEDA LACRYMA, Sow.

1824. *Nucula caudata*, Sow. Min. Conch. t. 476.

1853. *Leda lacryma*, Morr. & Lyc. Gt. Ool. Moll. pt. 2, t. 5. fig. 15.

1869. *L. lacryma*, Brauns, Mittl. Jura, p. 264.

There is a poor specimen from the base of the Inferior Oolite at Dundry, which appears to belong to this species. Dr. Brauns and Morris and Lycett give long lists of synonyms.

#### CARDIUM DUNDRIENSE, n. sp. Plate XVIII. fig. 8.

1867. ? *Cardium cognatum*, Laube, Bivalven von Balin, t. 4. fig. 2.

Shell almost exactly circular, globose, nearly smooth. Umbones prominent, central, direct, gently curving over the hinge-line. Sides nearly similar, the antero-superior portion being rather more depressed, and the margin rather produced at the lower posterior corner. Hinge with a distant lateral tooth on each side. Margins meeting all round at a moderate and equal angle. Surface with very fine concentric lines, crossed posteriorly by indistinct rounded swellings, but with no signs of radiating lines.

*Locality.* One specimen from Dundry in the British Museum.

*Dimensions.* 23 lines long by 22 broad, and 16 deep for the closed valves.

This shell is very different from that figured by Phillips as *C. cognatum*. It would agree in shape with Morris and Lycett's figure and description of the same shell; but it differs from that and all the shells which I have seen referred to Phillips's species by the total absence of radiating lines, which, though not appearing on Phillips's figure, seem universally acknowledged as belonging to his shell. Their absence in the specimen is the more evident, because the concentric marks are very distinct, and, just in the part where they should be covered by rays, some small Polyzoa are attached, which are wonderfully sharp and defined even under a lens. Mr. Tawney has referred it to Phillips's species, and it may prove to be only a variety of that shell.

Leckenby, in giving a corrected figure in the Quart. Journ. Geol. Soc. vol. xv. t. 3. fig. 8, which shows the rays, states that it was impossible to recognize Phillips's species without a reference to the original specimens. Laube's shell, though without striæ, is wider, while *Isocardia clapensis*, Terq. & Jour. Mém. Soc. Géol. Fr. sér. 2, vol. ix. p. 11, fig. 13, though very near in general shape, is covered by fine radiations, which do not appear in the figure.

**CARDIUM PULSATUM, n. sp.** Plate XVIII. figs. 9, 9a.

Shell subspherical, nearly circular. Umbones large and prominent, but incurved so as to extend considerably beyond the hinge-margin and to be proximate. Margins evenly convex, meeting at a small angle. Greatest depth a little behind the hinge-line. Surface smooth, except on the posterior part, where it is ornamented by about sixteen close, simple, rounded, and rather large longitudinal striae. Shell-structure very thin.

The closed shell measures 12 lines long, 10 wide, and 8 deep.

I have obtained this shell from the Inferior Oolite of Dundry. In the Jermyn-Street Museum there is a similar shell from the borders of Ponton Heath, near Grantham, and another and much larger specimen from Cold Comfort.

**LUCINA ? BURTONENSIS, Lyc.**

1863. *Lucina ? burtonensis*, Lyc. Suppt. Gt. Ool. Moll. t. 40. fig. 20.

Shell orbicular, very flat, smooth. Umbones central, very small, not rising above the general surface, acute and pointed forward. Lunule indistinct. Escutcheon lancet-shaped, bounded by a distinct angle. Ventral margin slightly less rounded than the others. Valves meeting at a very small angle. Surface flatter posteriorly, almost smooth, having numerous flat, minute concentric markings of rather unequal width.

There are two small specimens of this Forest-Marble shell among the Dundry specimens in the Bristol Museum.

**KELLIA ETHERIDGII, sp. n.** Plate XVIII. figs. 12, 13, 13 a.

Shell transversely ovate, almost the exact shape of an egg, convex, attenuated behind. Front margin moderately convex; posterior margin very convex. Umbo very anterior, situated about one fourth along the width of the shell, direct, minute, and incurved, just appearing above hinge-line. Hinge-line curved; two distant very distinct teeth on the left valve, and two indistinct diverging ones on the right valve. Surface covered with unequal, sharp, distinct, thread-like concentric lines.

It is about a line in length.

Two specimens from the Barnack Rag in the Sharp Collection in the British Museum.

These pretty little shells are very nearly allied to those figured by Sowerby from the Cretaceous rocks.

**SPHÆRA FIMBRIATA, n. sp.** Plate XVIII. figs. 10, 11.

Shell orbicular, very convex, somewhat produced and flattened at the superior corners. Umbones rather small, distinct, rounded, proximate, slightly anterior and curving subspirally forward. Margins nearly equally convex, inclined to each other at a moderate angle. Hinge-line curved, with a prominent rounded tooth just in front of the umbo, and a larger, longer, and more indistinct one behind. Ligamental groove long, narrow, and external. Lunule indistinct,

divided by the raised margins of the shell. Surface covered with about 70 low, close, distinct, and very rounded rays, crossed by numerous concentric regular lines which form frills with the rays, and give the shell a kind of tessellated appearance. Test very thick.

*Dimensions.* 10 lines long, 11 wide.

Two specimens in the British Museum from Dundry, and one in my collection from the *Parkinsoni*-zone of Bradford Abbas. There are similar shells from the same locality at Jermyn Street.

This form much resembles *Sphæra madridi*, D'Arch., except in its ornamentation and its more dilate margins. Though Morris and Lycett, after examining specimens of all ages, described that species as smooth, there must remain some doubt whether the present shell is more than an extreme variety of it.

*SPHÆRA CRASSICOSTA*, D'Orb., sp. Plate XVI. figs. 16, 16 a.

1849. *Corbis crassicosta*, D'Orb., Prodr. sect. 11, no. 239.

1867. *Sphæra crassicosta*, Laube, Bivalven von Balin, t. 3. figs. 5, 6.

There are three small spherical shells from Nailsworth in the Jermyn-Street Museum, which perhaps belong to this species. Being closed valves and partly imbedded in matrix, they are difficult to decipher; but they are smaller and deeper than the specimen figured by Laube. The lunule is smoother, and the escutcheon deeper, though both are undefined. The umbo seems less prominent. The valves are very thick and meet perpendicularly. The shell measures about one line, and possibly may prove to be an *Astarte*.

*ASTARTE ANATIFORMIS*, n. sp. Plate XVIII. fig. 14.

Shell large, flattened, attenuated behind. Umbo anterior, acute, proximate and prominent. Lunule sharply excavate, but very flat and shallow. Area small, with a deeply incised line from the exterior ligament. Margin concave in front of the umbo, then becoming very convex on the anterior side, and moderately so on the inferior parts, extremely convex on the posterior side, where the shell is narrowed and depressed, and straight behind the umbo. Hinge large, with one large central tooth and two less distinct lateral ones. Surface covered with numerous faint, irregular, concentric marks, divided into groups by nine or ten deeper lines.

Length 21 lines, breadth 27, width 8 for the double shell.

There are two specimens of this species in the Jermyn-Street Museum, from Nailsworth.

*ASTARTE CRASSITESTA*, F. A. Römer.

1839. *Astarte crassitesta*, F. A. Römer, Verst. ool. Geb. Supt. t. 19. fig. 18.

1842. *A. crassitesta*, F. A. Römer, De Ast. Gen. p. 11.

1878. *A. Mansellii*, J. Buckman, Proc. Dorset. Nat. Hist. Club, vol. ii. t. 6. fig. 3.

The shell described by Mr. Buckman, and which is common at Half-way House, does not seem to be distinguishable from Römer's species.



*ASTARTE ELEGANS*, var. *MUNDA*. Plate XIX. fig. 4.

Shell large, transverse, moderately convex. Umbo small, incurved, rounded, prominent, and situated at one quarter of the diameter from the anterior margin. Lunule small and extremely deep. Inferior margin slightly convex; anterior and posterior very much so, the anterior side being much smaller than the posterior one. Shell-substance massive. Surface covered by about forty-five prominent, rounded, transverse ridges, which unite in sets of three or four near the lunule, and are separated by concavities of the same size as the ridges.

Size of the closed shell 21 lines long, 27 wide, and 10 deep.

There are two specimens of this fine shell in my collection from Hardington, near Yeovil. It is so unlike ordinary specimens of *A. elegans*, even when they approach its size, in the greater roundness and irregularity of its ribs as well as in being a flatter shell, that I am much inclined to regard it as a distinct species. From *A. detrita*, Goldf., t. 134. fig. 13, it differs through its flatness and the number of its ribs.

*ASTARTE MAGNALIS*.

1857. *Astarte cordiformis*, Lycett, Cottes. Hills, p. 126.

Lycett's name for this species from the *Parkinsoni*-beds of Rodboroug requires to be changed, as Deshayes had before used the same name for a different shell. He describes it as shorter and more tumid than *A. rhomboidalis* (Ph.), and destitute of plications.

*ASTARTE SUFFLATA*, Röm. Plate XVIII. figs. 15, 15 a, 16, 16 a.

1842. *Astarte sufflata*, F. Römer, De Ast. Gen. t. 1. fig. 5.

1849. *A. cordiformis*, D'Orb., Prodr. vol. i. sect. 10, no. 281 (pars).

1867. *A. sufflata*, Laube, Bivalven von Balin, p. 36.

Shell thick, orbicular, very convex, slightly broader than long. Umbones very prominent, compressed, rounded, proximate, and slightly anterior. Lunule and escutcheon indistinct. Margin rather concave in front of umbo, otherwise convex, rather produced at the posterior basal angle. Surface rounded, covered with about twenty-four flattish inverted ridges (so as to give a saw-like section with teeth facing apex). Just behind the central line of the valve spring a corresponding number of grooves, dividing each ridge into two unequally high parts. Hinge-line curved. Teeth on the left valve distant and short, there being a wide central groove between them. Edges with coarse dentations within.

Length 7 lines, breadth 7, depth 6.

Whether Römer is justified in separating this shell from *A. cordiformis*, Desh. Enc. Méth. vol. ii. p. 80, on account of the obscurity of its lunule and escutcheon, seems an open question. In its even surface-markings, though like some recent shells, it differs from any other Oolitic forms with which I am acquainted.

There are four specimens in the British Museum from Dundry, and three in the Bristol Museum labelled "Hampton Common." I

have never found it myself. *A. cordiformis*, Desh., seems to be a common form at Des Moutiers and Bayeux, many specimens from those localities being in the British Museum.

ASTARTE UNGULATA, Phil., sp.

*Astarte lurida*, Phill. Geol. York. vol. i. t. 5. fig. 2 (non Sow.).

*A. ungulata*, Lycett, Supp. Gt. Ool. Moll. t. 35. fig. 20.

This shell is fully described in the Palæontographical Society's Monograph as an Oxfordian and Cornbrash fossil. In the Bath Museum there is a specimen from the Inferior Oolite of Dinnington, Somerset; and I have obtained it from the *Parkinsoni*-zone of Burton Bradstock.

GOULDIA? OVALIS, Quenst., sp. Plate XVIII. figs. 17, 17 a.

1852. *Cardita ovalis*, Quenst. Handb. t. 56. fig. 22.

1852. ? *C. problematica*, Buv. Stat. Géol. de la Meuse, t. 15. figs. 18-23.

1858. *C. ovalis*, Quenst. Jura, t. 93. fig. 33.

1871. *Corbis oviformis*, Terq. & Jour. Mém. Soc. Géol. Fr. sér. 2, vol. ix. t. 10. figs. 30-33.

Shell convex but flattened, small, massive, and obliquely transverse. Umbo small, acute, proximate, anterior and facing forward. Lunule indistinct. Ligament external. Teeth 2, 1; lateral 1-1, 1-1. Pallial line entire. Muscle-marks at the extremities of the long hinge-line, raised, but concave. Edges crenulated within. Margins: anterior convex, inferior nearly straight, posterior convex below and oblique above. Surface flattened on the back, but in the full-grown shell nearly perpendicular near the borders, covered with very fine transverse striæ and a few indistinct growth-lines. Shell-structure thickest near the inferior margin.

*Dimensions*. Length 5 lines, width  $6\frac{1}{2}$  lines, depth of one valve 4 lines.

There are two specimens in the Bristol Museum from Bradford Abbas, and I have obtained many from the *Humphriesianus*-zone of the same locality.

The figure in Quenstedt's 'Handbuch' agrees exactly with the British shell; but in that in his 'Jura' the hinge is incorrectly given, which might easily have arisen from the fossil from which it was drawn having been clogged with matrix. Buvignier's *C. problematica* may belong to this species, though its ornamentation is much coarser; but *C. Moreana* of the same author is a slighter and wider shell, and differs in the character of its hinge. *Astarte rhombea*, F. Röm. de Ast. Gen. t. 1. fig. 3, has a smaller anterior side, and is less thickened at the margins.

GOULDIA? MITRALIS, n. sp. Pl. XVIII. figs. 18, 18 a.

Shell small, oblique, very transverse. Umbo anterior, acute, small, curved forward. Hinge long, with two very divergent central

teeth enclosing a groove, and one large posterior lateral tooth on the left valve. Ligament exterior? Lunule undefined. Margins slightly concave in front of the umbo, very convex anteriorly and at the infero-posterior angle, straight below, and oblique posteriorly. Surface flattened centrally, but becoming suddenly steep near the margins, covered with numerous close, concentric, indefinite striæ or growth-lines. An obtuse angle runs from the umbo to the infero-posterior corner. Edges smooth within. Structure very thin, except at the margins, which are thickened.

*Dimensions.* Length  $3\frac{1}{2}$  lines, breadth 6 lines, depth 3 lines for both valves.

This shell, of which I have a single specimen from the *Humphriesianus*-zone of Bradford Abbas, is very similar to *Gouldia*? *ovalis*, but is thinner and more transverse, and has a more prominent umbo and a smooth straight inferior edge. From *Cardita Moreana*, Buv. Géol. Meuse, t. 15. fig. 29, it differs by the presence of a posterior tooth.

CYPRICARDIA FILOPERTA, n. sp. Plate XVIII. figs. 19, 19a.

Shell small, transverse, flatly convex, subquadrate. Umbones rather small, but well defined and prominent, proximate, anterior (being two thirds the diameter from the rear) slightly curving anteriorly. Lunule small, ovate, deep. Escutcheon very narrow, long and lanceolate. Hinge-line oblique, long and straight. Anterior side narrow and very regularly convex. Inferior and posterior margins crenulated within, very slightly convex, and meeting each other at a highly curved corner, to which point an indistinct oblique angle runs down the shell from the umbo, behind which the surface is slightly concave. The whole surface covered with exceedingly numerous, regular, acute, prominent, threadlike, concentric lines, of almost the same size, from umbo to margin, and with a few greater undulations beneath them. Shell-structure extremely thick, probably half the mass of the fossil being composed of the shell. Valves meeting at a very small angle.

*Dimensions* of the closed shell:—Length 9 lines, width 10 lines, and depth 6 lines.

There are two specimens from Dundry in the Bristol Museum, and one in the British Museum, from Les Moutiers, France; but I have been unable to identify it with any described form.

OPIS SPATHULOSUS, n. sp. Plate XVIII. figs. 20, 20a.

Shell flattened, very slightly convex, not oblique. Umbo exceedingly prominent and produced, central, flattened, bending gently forward, but comparatively erect; its apex being subacute, slightly curving inward, but distant. Lunule extremely deep and hollow, with well-developed flattened sides and defined subangular edges, the surface in front of the umbo turning rapidly round and doubling almost upon itself to form it. The anterior side much produced. The line of contour starting from the apex, being, for nearly half the length of the shell, concave (round the edge of the

lunule), then curving suddenly and directly forward for some distance, and then coming rapidly round the very convex anterior side to form the almost straight inferior margin. The posterior side seems to be bounded by two nearly equal straightish lines, one coming down the back of the umbo very obliquely and meeting a rather longer one, which is almost at right angles to the inferior side. There are indications of an angular ridge from the beak to the posterior corner; but the type specimen being defective in this part, it is impossible to be certain as to these characters.

Surface covered with about thirty rather obliquely flattened, reflex, transverse ridges, separated by grooves of a similar size, becoming indistinct on the beak.

One specimen in the Sharp Collection in the British Museum, from "Store Nine Churches, near Weedon," and others in the Jermyn-Street Museum, from the Cornbrash of Appleby, Lincolnshire.

It bears much resemblance to the huge *Opis trigonalis*, Sow.; but besides being distinguished by the very great difference in size, the lunule seems to be deeper, the umbo more erect, and the general contour more squared.

*MYOCONCHA UNGUIS*, n. sp. Plate XVIII. fig. 21.

Shell elongate, oblique, recurved, flat, very massive. Hinge extremely developed, especially in the anterior direction, where the umbo curves down to form a massive hook. External groove very well marked. Margins convex superiorly, dilate behind, concave below. Shell-structure extremely massive, consisting of coarse growth-layers which overlap the margins, except in the posterior parts. Surface slightly and irregularly convex, crossed towards the rear by the upper growth-layers.

*Dimensions.* Length  $5\frac{1}{2}$  inches, breadth  $3\frac{1}{2}$  inches.

There is a specimen of this shell in the Bristol Museum, from the Inferior Oolite of Dundry, and two similar ones in the Jermyn-Street Museum from Bradford Abbas.

It differs from old specimens of *Myoconcha crassa* by the extremely elongated and hooked anterior extremity. The great development of shell gives it a superficial resemblance to an oyster, but the internal scars are very clear and typical.

*MYOCONCHA IMPLANA*, n. sp. Plate XVIII. fig. 22, and Plate XIX. fig. 5.

Shell trigonal, very oblique and transverse, angularly convex. Umbones small, subterminal, facing forward. Hinge-line very long, being more than three fourths of the breadth of the shell, straight, and with a groove running the whole length of its external surface. Front wing small, and very convex. Hind wing very much produced. Anterior margin convex. Inferior margin oblique and straight. Infero-posterior corner sharply rounded. Posterior margin oblique, nearly straight, meeting the hinge-line at an obtuse angle.



The umbones form an obtuse ridge, which is continued in a slightly spiral line to the infero-posterior point; from this ridge the surface slopes flatly to each side, becoming slightly concave near the margins. Surface with coarse striations formed by the growth-lines and a few very delicate and distant thread-like radiations.

This shell occurs frequently at Dundry in the state of casts, and there are several specimens of it in the Bristol Museum. In the Jermyn-Street Museum and my own collection there are specimens from Bradford Abbas and from Half-way House with the shell preserved.

*Dimensions* of the closed shell:—Length 33 lines, width 17 lines, depth 10 lines.

The Dundry casts were considered by Mr. Tawney to belong to the genus *Myoconcha*, which appears to be borne out by the shells in the Jermyn-Street Museum.

Of Sowerby's shells *Modiola Hillana* comes nearest in shape, but has a much shorter hinge-line, which is not one half the length of the shell. *Modiola imbricata*, Sow. t. 212. figs. 1–3, differs in its shorter hinge-line and larger anterior side, as well as in its concave inferior margin. Morris and Lycett's figure of that shell is different from Sowerby's. *Myoconcha actæon*, Morr. & Lyc., is a rounder and flatter form, without the protruding ear, the shelving sides, and the triangular shape which so strongly define this species.

**THRACIA LEGUMINOSA**, n. sp. Plate XVIII. figs. 23, 23 a.

Shell flattish, very transverse, bean-shaped. Umbo minute, situated two thirds of the way back, and slanting, but not facing posteriorly. No lunule or escutcheon. Edges meeting all round at a similar and very acute angle. Dorsal and ventral margins nearly parallel, the latter being slightly concave. The side margins convex, the anterior being considerably the larger. The antero-dorsal region slightly flattened from an indistinct angle. The shell-substance very smooth, thin, and shining.

*Dimensions* of the closed shell:—3 lines long, 5 wide, and  $1\frac{1}{2}$  deep.

*Locality*. Dundry. Two specimens are in the Bristol Museum.

The nearest approach in general shape to this fossil is *Quenstedtia laevigata* of Morris & Lycett, Gt. Oolite Moll. pt. 2, t. 14. figs. 13; but in this the posterior side is smaller and the umbo larger. *Myacites jejunus*, Quenst., Jura, t. 68. fig. 6, also bears much resemblance to it; but in that shell the inferior side is convex and the umbo less elevated. In shape it is similar to, but more angular than, *Cyclas faba*, Münster, Goldf. t. 147. fig. 8, from the Wealden. It is evidently most closely allied to *Venus liasina*, F. A. Römer, Verst. ool. Geb. t. 14. fig. 10, but would seem to be a somewhat less equilateral and transverse shell.

**THRACIA STUDERI**, Ag. Plate XIX. fig. 6.

I have obtained from Bradford Abbas a specimen which appears to agree with the shell figured by Agassiz, Et. Crit. p. 267, t. 35, and there are two from Bradford in the Jermyn-Street Museum.

It is very transverse, inequivalve, with a long escutcheon, the anterior side angulated, the posterior produced and squared, and very slightly gaping.

It is very similar to *Mya depressa*, Sow. Min. Conch. t. 418, in general shape, but differs in the squared and flattened anterior part, and in the almost angulated posterior margin.

Agassiz seems to have changed the name rather unnecessarily, and probably Thurmann's specific name, *Tellina incerta*, sp., Röm. Verst. ool. Geb. t. 8. fig. 7, should be restored.

*PHOLADOMYA CALLÆA*, n. sp. Plate XIX. figs. 7, 7a.

Shell moderately convex, ovoid, transverse, somewhat flattened behind. Umbones small, well defined, rather flattened and very anterior, being often less than one sixth of the diameter from the anterior side. Dorsal side long and straight. Escutcheon very long and lanceolate, bounded by strong sharp ridges. Posterior margin very convex, the line of margin being continued on the inferior side in a fine uninterrupted decreasing curve. Anterior side narrow and slightly convex. Valves meeting at a small angle. The posterior gape moderately long, invading the dorsal side, and very narrow. Surface with small, close, irregular concentric markings, and twelve or thirteen sharply marked but very fine rays, which are simply breaks in the continuity of the surface, curving somewhat backward, and vanishing in the marginal parts. Test very thin.

*Dimensions.* Length 22 lines, width 36 lines, depth 16 lines.

This form is remarkable for its small anterior umbo, fine radiations, and generally symmetrical shape. It seems common in the ironshot-beds of Dundry. There are specimens in the Bristol and Jermyn-Street Museums, and I have obtained several from the quarry near the cross roads at that place.

From *Ph. oblita*, Morr. & Lyc. pt. 2, p. 142, and Lyc. Suppl. p. 120, it differs in the character of the umbones, the length of its anterior side, the less rounded form, and, according to the description only, the smaller number of rays.

It undoubtedly approaches very near to *Ph. ovulum*, Ag. Et. Crit. t. 3. figs. 7-9, and t. 3b. figs. 1-6, but seems to me distinct on account of its smaller, more defined and terminal beak, squarer anterior side, and more thread-like rays. Lycett's shell, Suppl. t. 35. fig. 18, is very dissimilar, and Agassiz's original conveys the idea of a more oblique and strongly ribbed form. The variety figured by Mösch, Pal. Suisse, vol. i. t. 20. fig. 4, approaches it most nearly, though still having the anterior side more rounded.

Some smaller shells from Dundry in the Bristol and Jermyn-Street Museums, and from Bradford Abbas in my collection, agree very fairly with typical specimens of *P. ovulum* like that figured by Laube, t. 5. fig. 2. They are convex and ovoid, with large and more central umbones (situated two thirds forward), have the side margins curved, and have twelve rather prominent ribs. My own belief is that these belong to a different species from the former; but considering the immense variability of the *Pholadomyæ*, it is impos-

sible to speak with certainty. Certainly the larger figures of *Ph. ovulum*, especially those of foreign authors, are very different from the larger Dundry forms, which seem to have well-defined characteristics of their own.

*PHOLADOMYA FORTIS*, n. sp.? Plate XIX. fig. 8.

Shell moderately convex, ovate, rather flattened inferiorly. Umbones subcentral, direct, large, but low, and rather compressed. Escutcheon long, bounded by a strong ridge. Front and rear margins apparently convex; inferior margin nearly straight. Surface with irregular concentric marks, which are sharp and occasionally prominent, and with eleven very distinct and distant linear ribs reaching the margins and spreading over the whole shell. Test very thick.

*Dimensions.* Length  $1\frac{1}{4}$  inch, width 2 inches, depth 1 inch.

I should have been inclined to suppose these shells, of which I have obtained two or three rather imperfect specimens from Dundry, to be a variety of *Ph. ovalis*, Sow., were it not for the very great thickness of their tests; for although Sowerby supposes one of his shells to have this quality, it is the one he obtained from the Portland-beds, and which does not at all agree with the present shell in other particulars. In the specimens of that species described by Morris and Lycett, whose figures are more like the present shell than are Sowerby's, the test appears to be of the usual thinness in this genus; and I have obtained other shells from Dundry agreeing with their figure, and therefore, as I suppose, the true *Ph. ovalis*, Sow., which are certainly distinct from the present species.

It also bears great resemblance to *Ph. tumida*, Ag., which, with other species, Mösch unites with *Ph. canaliculata*, Rö.; but I find no mention of their having thick shells, and this, if it had been so, would have been almost sure to be mentioned from its rarity in this genus. It must therefore remain doubtful whether they belong to this species.

The name "*Ph. angustata*, Sow.," is often found in lists and labels of Inferior Oolite shells. I believe that this is because his figure has the appearance of being foreshortened, and is therefore supposed to be less transverse than is the fact. However, on examining his original specimens, it is at once seen that they are accurately represented by his drawings. I do not think this form ever occurs in the Lower Oolites, but that when the name is so used, it is applied to lengthened specimens of *Ph. ovalis*.

*PHOLADOMYA NEWTONII*, n. sp. Plate XIX. figs. 9, 9a.

Shell small, flatly convex, subtriangular. Umbo anterior, small, rather incurved. Anterior side large, swollen, and convex; posterior much attenuated, and flatter. Margins convex, especially the anterior one. Escutcheon broadly lanceolate, bounded by a strong keel to the posterior end. Surface covered by numerous regular, well-defined concentric furrows, and crossed by a few faint rays.

*Dimensions.* Length 12 lines, width 16 lines, depth 8 lines.

This little shell from Bradford Abbas differs from *Pholadomya bellula* by its peculiar shape and finer markings. The variety of *Ph. ovulum* given by Mösch in Mem. Pal. Suisse, t. 20. fig. 5, which seems to resemble this shell, chiefly does so because the Swiss specimen is injured and incomplete behind; while *Ph. paradoxa*, Ag., and other species approaching it in general form, are all strongly radiated or keeled. *Ph. orbiculata*, Röm. Verst. ool. Geb. p. 132, of the Portlandian, is more angulated and oblique, with strong ribs.

*PHOLADOMYA BELLULA*, n. sp. Plate XIX. figs. 10, 10a.

Shell small, oval, very convex, slightly transverse. Umbo very large and anterior, elevated, tending rather forward and much incurved. Escutcheon long and large, bounded by very sharp and raised borders. Anterior margin obliquely rounded, inferior arched, and posterior rather narrow and convex. Surface with numerous, regular, deep striæ, dividing it into broad, flattened, transverse plaits, the whole covered with crowded finer striæ, and crossed by nine lines of strong radiating knots, only visible on the plaits, and arching backwards near the margins.

*Dimensions.* Length 10 lines, breadth 13 lines, depth 9 lines.

There are two specimens of this shell from Bradford Abbas in the Jermyn-Street Museum and one in my own collection. It is a very neat, highly ornamented form, and seems to me well marked, being distinguished from *Ph. Heraulti*, Ag. (= *Ph. Murchisoni*, Sow., pars), by its defined escutcheon, and from *Ph. socialis*, Chapuis (non Morr. & Lyc.), Foss. Lux. Suppl. t. 12. fig. 1, by that and by its knotted ribs.

The Liassic species, *Ph. Simpsoni*, Tate and Blake, Yorkshire Lias, t. 12. fig. 8, which is stated to com between *Ph. Dewalquea* and *Ph. ambigua*, is smooth behind, and these three shells have unkeeled escutcheons.

From *Ph. concinna*, Ag. loc. cit. t. 7a. fig. 1-6, it is distinguished by its much more elevated beaks.

*PHOLADOMYA SPATIOSA*, n. sp. Plate XIX. fig. 11.

Shell large, ovate, deeply convex, transverse. Umbo large and prominent, round and anteriorly curved, considerably raised above the hinge-line. Escutcheon small and indistinct, without bounding ridges. Dorsal side straight; posterior side broad and flatly convex; inferior side slightly convex and oblique; anterior side rather attenuated, rounded above and oblique below. Test thin. Surface covered with very numerous and irregular concentric striæ, which nodulate the oblique ribs, of which eight are rather prominent, and reach the margins in a backward curve (the second front one being the largest), and two, one each side, are more indistinct and only visible near the umbo, so that the lateral portions of the shell are smooth. Gape very long and narrow.

*Dimensions.* Length  $3\frac{1}{2}$  inches, breadth  $4\frac{1}{4}$  inches, depth  $2\frac{1}{2}$  inches.

There are fine specimens in the Jermyn-Street Museum, in my own collection, and especially in the British Museum, from the ironshot beds of the *Humphriesianus*-zone of Dundry.



This handsome species seems very like *Ph. nodosa* of the *Obtusius*-zone, Goldf. Petr. Germ. t. 156. fig. 5, but its umbones are more prominent, so that the dorsal profile of the shell presents two sweeping concave curves. Mösch has sunk Goldfuss's name as a synonym of *Ph. idea*, D'Orb., v. *Deshayesii* (Chap. & Dew.), though Goldfuss certainly has the priority. At all events, if his identification is correct, our species is certainly distinct, and, indeed, belongs to a different section of the genus, as D'Orbigny's shell has well-defined shield-borders, which are wanting in the present one.

From Sowerby's longer figure of his *Ph. Murchisoni* it differs by not having such massive ribs and some other particulars. Mösch reunites to that shell the form *Ph. Heraulti*, which Agassiz, followed by Lycett &c., had distinguished from it. The observation of many Dundry specimens has always led me to regard the latter authors as correct in this; but, in any case, it is clearly different from the present species, and in fact occurs in a higher bed from that in which this is found.

*Ph. producta*, Sow. Min. Conch. t. 197. fig. 1, approaches it more closely, but in it the umbo is less central, and the rays larger, more distant, and spreading over the anterior side. Mösch, loc. cit. p. 39, identifies this shell with *Ph. deltoidea*; and if he is right, it has not the least to do with the one under consideration, being much longer and altogether of another shape.

From *Ph. frickensis*, Mösch, loc. cit. t. 10. fig. 1, it is distinguished by its much less terminal umbo and more distant rays. Compared with *Ph. Wittlingeri*, Waag. Ben. Geogn.-Pal. Beitr. p. 614, of which there is a specimen among the Inferior Oolite fossils of the British Museum, and which has the same prominent second rib, it is wider, with much longer and more defined umbo, and its anterior side is more produced above and obliquely truncated below. However, the two forms are so similar that I do not feel positive that they are distinct species.

*Ph. media*, Ag. loc. cit. p. 72, is very like it in ornamentation, but more rounded in shape, with a smaller less-defined beak and obtusely bounded escutcheon. Again, it comes much nearer to *Ph. nymphææa*, Ag. loc. cit. p. 71, in the former particulars; but in that the escutcheon is described as very large, deep, and obtusely bounded, and the muscle-mark is smaller.

**MYACITES SUBSIDENS, n. sp. Plate XVIII. figs. 24, 24a.**

Shell transverse, convex, but centrally flattened. Umbones rather anterior, facing anteriorly, and much incurved, truncated in front by a curving rounded angle, expanded backward. The cardinal areas defined by prominent obtuse ridges in both directions. The anterior and posterior margins deeply and nearly equally convex, the inferior margin slightly so. The larger portion of the surface between the umbones and the inferior margin is laterally flattened, and covered with coarse prominent concentric ribs or growth-lines, which vanish rather suddenly as they approach the lateral margins.

I have obtained several specimens of this shell from Dundry. There is a fine specimen in the British Museum and two at Jermyn Street from Leekhampton.

*Dimensions.* About 10 lines in length and 13 lines in width.

The central prominent and flattened umbones, together with the ribbed central and smooth lateral portions of the surface, serve to distinguish this shell, and I have not met with any species with which I have been able to identify it. The specimen figured, being an injured one, hardly shows its characters so well as might be wished.

*TEREBRATULA TAWNEYI*, n. sp. Plate XIX. figs. 12, 12a, 12 b.

Shell small, orbicular, flattened dorsally, convex ventrally. Beak moderately incurved and protruding upwards. Foramen very large, bounded by the summit of the dorsal valve. Deltidium absent. Ventral valve moderately convex. Dorsal valve only slightly so. Margins nearly circular. Slight indications of a very wide and flat fold. Hinge-area small, linear. Surface covered with numerous fine rounded ribs, arranged in irregular groups by every third or fourth one becoming more prominent; these lines reach and cover the umbo. Shell-structure with exceedingly large and coarse puncta, arranged in curving rows.

I have found a single specimen of this beautiful little shell in the upper beds of the *Humphriesianus*-zone at Dundry.

*Dimensions.* It is about 6 lines in length and width and 3 in depth.

Dr. Davidson, who has very kindly examined the fossil, informs me that he considers it to be new.

In naming it after our much lamented friend, Mr. Tawney, by whose admirable arrangement of the fossils in the Bristol Museum I have been much helped in the examination of these shells, I cannot help bearing witness to the greatness of his loss to science; but his persevering energy, accuracy of knowledge, and quickness of observation cannot make his early death more regretted among geologists than the kindness of his disposition, experienced by myself on many occasions, has done among his friends.

*RHABDOCIDARIS THURMANNI*, De Lor., var. *REGENS*. Plate XIX. figs. 13, 13a, 13b.

I have obtained a fragmentary spine of *Rhabdocidaris* from the upper beds of the *Humphriesianus*-zone at Dundry, in which *Mangotia Forbesii* not unfrequently occurs, as well as other Echinoderms, *Thecidia triangularis*, and some small sponges. It is much flattened, with expanding sides, convex shoulders, and small neck. The upper surface is covered by exceedingly numerous and fine nodulous lines, which become coarser and more distant on the sides and lower surface, down the centre of which runs a wide arching groove. The shoulders are covered with coarser spines.

*Dimensions.* Width about 1 inch, depth  $\frac{1}{2}$  inch.

It appears very like Desor and De Loriel's figure of *Rhabdocidaris Thurmanni*, in their 'Echinologie Helvétique,' t. 9. figs. 2-4, and

t. 61. figs. 2, 3. They give as synonyms *Cid. spatula*, Thurm. (non Ag.), and *C. copeoides*, Quenst. (non Ag.), stating that it differs from *C. copeoides*, Ag. Cat. Ech., by its narrow and often long neck, fine marks, and absence of large spines at the base, and often is several inches in length. In our specimen the presence of large basal spines is very evident, but in other respects it might well agree with the Oxfordian form, so far as its upper surface goes, while it differs more from *Rh. copeoides*, Ag., in Desor's 'Synopsis,' p. 41, and t. 9. figs. 3-7, both in the shape of its shoulders and the fineness of its markings. The latter is quoted from the Inferior Oolite as well as the Oxford Clay of the continent. *Cidarites remus*, Quenst. Jura, t. 48, fig. 25, and t. 79. fig. 61, seems to differ in the presence of a row of coarse lateral teeth or spines, and, as figured in the new edition of his 'Petrefactenkunde,' seems very unlike.

Considering the differences displayed (especially if the median groove be a permanent character) and lowness of the horizon, it seems to me most probable that this will prove to be a distinct species; but, from the insufficiency of the material at command, I have merely given it for the present as a variety of the form which seems to approach most nearly to it.

**CHIRODOTA CONVEXA, n. sp.** Plate XIX. figs. 14, 14*a*.

Spicule with large central nucleus, from which spring seven spokes, which are flat, massive, and much arched, and increase in width towards the margin. These unite with the upper side of a vertically flattened circumference, which is in the same plane as the nucleus, and is compressed at the part where each spoke meets it, so as to present a rather seven-sided appearance. The peripheral band is of about the same width as the spokes, and curves inwards, so that its free margin, which is smooth, is rather nearer to the nucleus than the attached one.

This minute fossil comes from the Inferior Oolite of Burton Bradstock, and is very similar to that figured by Terquem & Jourdy in the Memoirs of the Geological Society of France, ser. 2, vol. ix. t. 15. figs. 8, 9. These organisms, which have occurred in the Oxfordian and Inferior Oolite of Würtemberg, the Great and Inferior Oolite of France, and the Inferior Oolite and Middle Lias of India, are supposed to be the spicules of Holothuroids; and the present fossil agrees in general form with recent specimens with which I have compared it.

**CHIRODOTA ? GRACILLIMA, n. sp.** Plate XIX. figs. 15, 15*a*.

Nucleus small, circular, with about fifteen fine convex rays, which join the upper side of a rather broad peripheral band, which is flattened perpendicularly to the plane of the circle and concavely to the nucleus. The free margin is notched with very numerous (26) small triangular teeth.

*Locality.* Burton Bradstock.

This is a much finer, slighter fossil than the last one, from which it entirely differs in appearance.

Of the Jurassic species, the Callovian *Ch. Sieboldii*, Schwager, Beitr. zur mikr. Faun. Jur. (Württ. Jahresh. 1865), t. 7. fig. 28, has ten spokes and very numerous long teeth; *Ch. atava*, Waag. Ben. Geogn.-Pal. Beitr. t. 24. fig. 4, from Gingen, is flatter, with expanded spokes, forming key-shaped openings, and *Ch. vetusta*, Schw., MS., Ben. loc. cit. p. 297, from the zone of *Amm. transversarius*, seems to differ in its convexity, the character of its periphery, and the arrangement of its lower side. Moore, in the British Association Report for 1872, refers to three Liassic and one Oolitic species occurring in England, and having rays varying in number from five to thirteen. The latter, *Ch. Carpenteri*, which is the only form he there defines, seems to be much more ornate than either of the two which are now figured. I cannot find that he has published any further description of his species.

#### EXPLANATION OF PLATES XV.-XIX.

In the following list, B.M. indicates fossils in the British Museum at South Kensington, J in the Museum of Practical Geology at Jermyn Street, and B in the Museum of the Bristol Scientific Institution, those without a letter being my own specimens. Where it was possible the figures and the measurements given in the text have been taken from different specimens of the same shells.

#### PLATE XV.

- Fig. 1. *Ostrea concentrica*, Münst., var. *munda*. Right valve. J.  
 2. — *Knorrii*, Voltz. Left valve; Bradford Abbas.  
 3, 3 a. — —. Left valve and profile; Fullers' earth, Frome.  
 4, 4 a. — *pyrus*. Left valve; Burnack. B.M.  
 5. — *sphaeroidalis*. Left valve; Yeovil Junction.  
 6. — —. Cast of left valve; Yeovil Junction.  
 7, 7 a. *Gryphaea abrupta*. Left valve, and profile seen from behind; Dundry. B.  
 8, 8 a. — *cygnoides*. Right and left valves; Broadwindsor. B.M.  
 9, 9 a. — *Sollasi*. Left valve, and profile of shell; Dundry. B.  
 10, 10 a. *Exogyra Davidsoni*. Left valve and hinge of the same, seen from the right. Frocester.  
 11, 11 a. — *globulus*. Cast of left valve, front view and profile; Duston. B. M.  
 12, 12 a. *Pecten fenestralis*. Right valve, and magnified surface. Bradford Abbas.  
 13, 13 a. — *intermittens*. Right valve and a portion of surface, magnified. Birdlip.  
 14, 14 a. — *spincostatus*, Eth., MSS. Right valve and magnified surface; Dundry. B.M.  
 15. — *demissus*, Ph., var. *inutilis*. Fragment showing colour, completed from another specimen; Yeovil Junction.  
 16, 16 a. *Placuna Rupertina*. Cast of left valve, showing hinge-line, cartilage-ridges, and muscular impression; and profile of the same valve; Duston. B.M.  $\times \frac{1}{2}$ .  
 17. — *sagittalis*. Right valve; Dundry.  
 18. *Harpax Tawneyi*. Interior of left valve; Dundry. B.  
 19. — —. Enlarged portion of another specimen, in which the hinge is more perfect; Dundry. B.  
 20. — *Parkinsoni*, Qu. Right valve; Yeovil Junction.  
 21, 21 a. *Plicatula Sollasi*. Right valve, nat. size and magnified 3 diameters; Dundry.  
 22, 22 a, 22 b. — —. Left valve, nat. size and magnified 3 diameters; and profile of the same specimen; Dundry.



## PLATE XVI.

- Fig. 1. *Pecten cornutus*, Quenst. Left valve; Bridport. J.  
 2, 2 a. ———. Left valve, nat. size; and front ear, enlarged  
 Leckhampton. J.  
 3. ——— *triformis*. Right valve; Northamptonshire. B.M.  
 4. *Plicatula sub serrata* (Münst.). Valve; Bradford Abbas.  
 5. ———. Ditto.  
 6. *Gervillia compressa*. Left valve; Nailsworth. J.  
 7, 7 a. ——— *gladiolus*. Right valve and profile of shell seen from above  
 Dundry. B.  
 8. ——— *intermedia*. Left valve; Frocester.  
 9. ———. Profile of left valve; Bradford Abbas.  
 10. *Pinna Dundriensis*. Portion of left valve. Dundry.  
 11. ——— *claviformis*. Left valve; Selsby Hill, near Nailsworth. J.  $\times \frac{1}{3}$ .  
 12. *Mytilus striatissimus*. Right valve; Dundry. B.  
 13, 13 a. ——— *primipilaris*. Left valve and profile of same; Stubbing-  
 ton. J.  
 14, 14 a. *Cucullea equata*. Right valve and profile; Freestone, Leck-  
 hampton. B.M.  
 15, 15 a, 15 b. *Macrodon rasilis*. Right valve, nat. size, and profile and  
 hinge-area  $\times \frac{2}{3}$ ; Bradford Abbas. B.  
 16, 16 a. *Sphæra crassitesta*, D'Orb.; Nailsworth. J.

## PLATE XVII.

- Figs. 1, 1 a. *Lima æpybolus*. Right valve and portion of surface, enlarged.  
 Broadwindsor. J. (Its convexity is the same as that of *Lima platy-  
 bolus*.)  
 2. *Lima amnifera*. Right valve; Yeovil Junction.  
 3, 3 a, 3 b. ——— *contorquens*. Right valve, profile, and magnified sur-  
 face; Northamptonshire. B.M.  
 4, 4 a. ——— *educta*. Left valve and profile; Leckhampton. J.  
 5. ——— *inoceramoides*. Left valve,  $\frac{1}{2}$  natural size; south of Perrott. J.  
 6, 6 a, 6 b. ——— *majestica*. Right valve and profile,  $\frac{1}{2}$  natural size, and  
 a portion of surface; Rodborough. J.  
 7, 7 a. ——— *placida*. Right valve and profile; Northamptonshire. B.M.  
 8, 8 a, 8 b. ——— *platybolus*. Left valve, profile, and magnified surface;  
 Nailsworth. J.  
 9. ——— *poetica*. Left valve; Dundry. B.  
 10. ——— *rodburgensis*. Right valve; Northamptonshire. B.  
 11, 11 a. ——— *seminuda*. Right valve and profile; Nailsworth. J.  
 12, 12 a. ——— *Sharpii*. Right valve,  $\frac{1}{3}$  nat. size, and portion of surface;  
 Brockhall. B.

## PLATE XVIII.

- 1, 1 a. *Arca culmotecta*. Left valve and profile; Dundry. B.  
 2, 2 a. *Macrodon? rapidus*. Right valve and magnified surface. Dun-  
 dry. J.  
 3. ———. Hinge-line,  $\times 2$ ; Dundry. B.  
 4. *Nucula subglobosa*, Röm. Bradford Abbas.  
 5, 5 a. ——— *nuciformis*. Front and hind profiles; Dundry. B.  
 6. *Isoarca capitalis*. Left valve; Rodborough. J. (Part of its mark-  
 ings have been obliterated in cleaning.)  
 7, 7 a. ——— *texata*. Left valve and profile; Nailsworth. J.  
 8. *Cardium dundriense*. Right? valve; Dundry. B.  
 9, 9 a. ——— *pulsatum*. Right valve, and profile seen from above.  
 Dundry.  
 10. *Sphæra fimbriata*. Left valve; Dundry. B.M.  
 11. ———. Hinge of right valve. B.M.

- 12, 12 *a.* *Kellia Etheridgii*. Right valve and hinge, both magnified; Barnack. B.M.
13. ———. Hinge of left valve, magnified; Barnack. B.M.
14. *Astarte anatiformis*. Right valve; Nailsworth. J.
- 15, 15 *a.* *Astarte sufflata*, Röm. Left valve and magnified surface; Dundry. B.
- 16, 16 *a.* ———. Interior and profile of another specimen; Dundry. B.
- 17, 17 *a.* *Gouldia? ovalis* (Quenst.). Right valve and interior of same; Bradford Abbas.
- 18, 18 *a.* — *mitralis*. Valve and hinge, magnified; Bradford Abbas.
- 19, 19 *a.* *Cypriocardia filoperta*. Left valve and profile seen from above; Dundry. B.
- 20, 20 *a.* *Opis spatulosus*. Right valve, and profile of the same. K.
21. *Myoconcha unguis*. Left valve; Dundry. B.
22. — *implana*. Profile of both valves, seen from above; Bradford Abbas.
- 23, 23 *a.* *Thracia leguminosa*. Left? valve, natural size and  $\times 2$ ; Dundry. B.
- 24, 24 *a.* *Myacites subsidens*. Right? valve and profile; Dundry.

## PLATE XIX.

1. *Ancyloceras Waltoni*, Morr. Burton Bradstock.
2. *Toxoceras Orbigny*, B. & S. Half-way House, near Yeovil.
- 3, 3 *a.* *Pecten puellaris*: nat. size and enlarged. B.M.
4. *Astarte elegans*, var. *munda*. Left valve; Hardington.
5. *Myoconcha implana*. Left valve; Bradford Abbas. N.B. The profile of the same shell is given in Plate XVIII. fig. 22.
6. *Thracia Studeri*, Ag. Valve; Bradford Abbas.
- 7, 7 *a.* *Pholadomya callæa*. Left valve and profile; Dundry.
8. — *fortis*. Left valve; Dundry.
- 9, 9 *a.* — *Newtonii*. Left valve and profile; Bradford Abbas.
- 10, 10 *a.* — *bellula*. Left valve and profile; Bradford Abbas.
11. — *spatiosa*. Left valve; Dundry. B.
- 12, 12 *a.*, 12 *b.* *Terebratula Tawneyi*. Dorsal and lateral aspects and magnified portion of surface; Dundry.
- 13, 13 *a.*, 13 *b.* *Rhabdocidaris Thurmanni*, var. *regens*. The upper and under surfaces of the portion of a spine and a section of the same, nat. size; Dundry.
- 14, 14 *a.* *Chirodota convexa*. Spicule seen from front and rear, highly magnified; Burton Bradstock.
- 15, 15 *a.* — *gracillina*. Spicule seen from front and rear, similarly magnified; Burton Bradstock.

*For the Discussion on this paper, see p. 553.*









INFERIOR-OOLITE FOSSILS

Mintern Bros imp

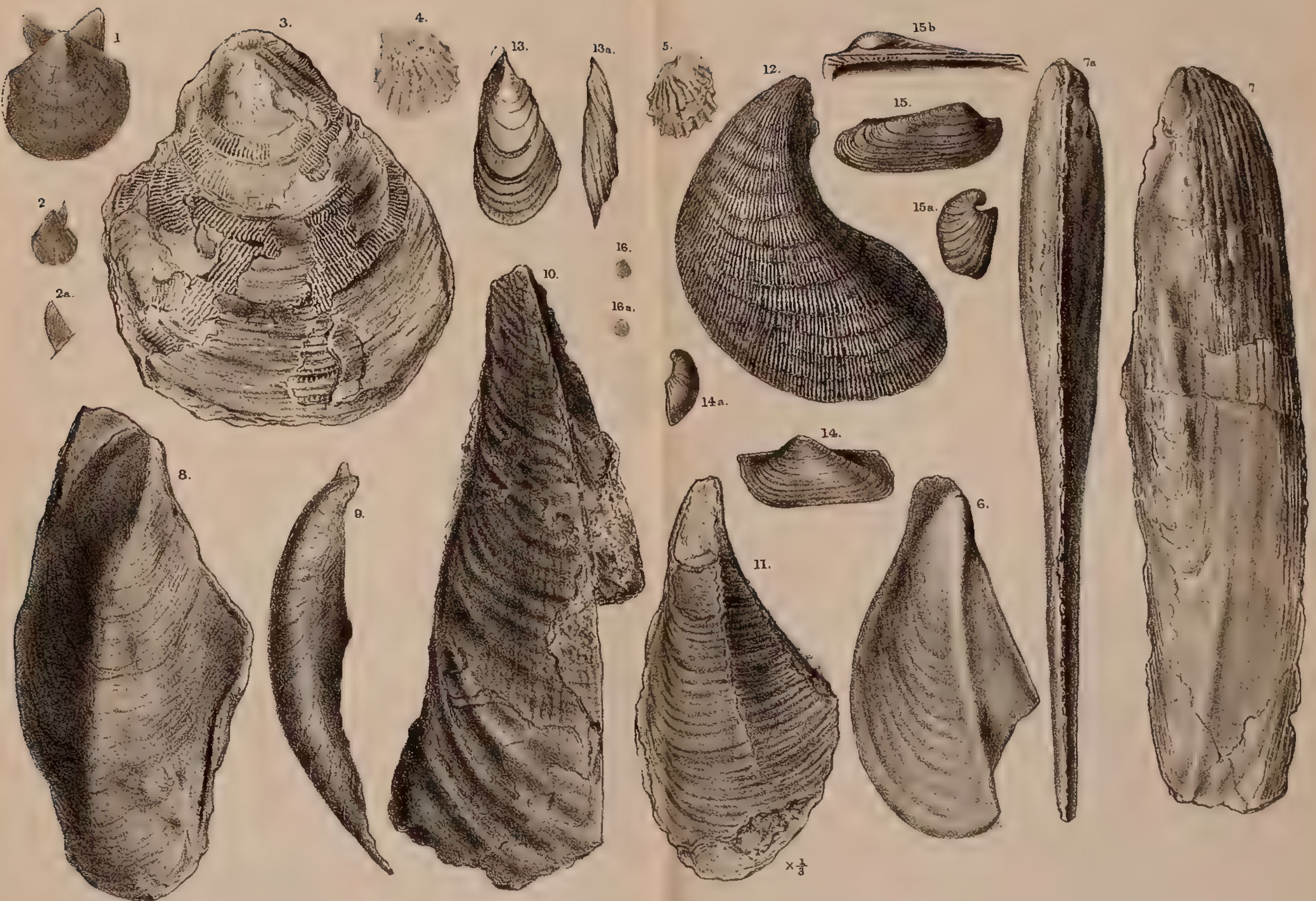
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INFERIOR - OOLITE FOSSILS.

Mintern Bros imp.































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Mintern Bros imp





29. DESCRIPTIONS of FOSSIL SPONGES from the INFERIOR OOLITE, with a NOTICE of some from the GREAT OOLITE. By Prof. W. J. SOLLAS, M.A., F.G.S., Fellow of St. John's College, Cambridge. (Read March 7, 1883.)

[PLATES XX. & XXI.]

SINCE up to this time the lists of palæontologists afford no instance of a fossil sponge from the Inferior Oolite of this country \*, we are the more indebted to my friend Mr. Whidborne for the rich representative collection of these forms amassed by his researches.

A preliminary account of this collection is published in the Report of the British Association for 1882, p. 534. I now proceed to offer a more detailed description of its contents.

## HEXACTINELLIDÆ.

### DICTYONINA.

#### EURETIDÆ.

#### EMPLOCA, gen. nov.

A cylindrical or ovate sponge, with thick walls surrounding the main excurrent canal, which, as a cylindrical tube, extends axially almost to the base of the sponge, and opens unconstrictedly at the summit in a circular oscule. The sponge walls are traversed by two sets of smaller canals, one incurrent, which, commencing in small round ostia evenly dispersed on the external surface, continue inwards obliquely downwards towards the axis; the other excurrent, which, crossing the incurrent canals, run more or less parallel to the curved upper margin of the sponge and finally open into the main excurrent canal. Skeleton Euretoid, *i.e.* a simple Dictyonine network with imperforate nodes; dermal skeleton not preserved.

The genus agrees in general form and in the characters of the

\* On the continent one or two species have been described from the Inferior Oolite, and quite lately Dr. E. v. Dunikowski (Denkschriften d. math.-naturwissenschaftlichen Classe d. k. Akad. d. Wiss. in Wien, Bd. xlv., 1882) has described many loose fragments and spicules of Hexactinellid network from still lower secondary strata, viz. the Lower Lias of the Schaffberg, near Salzburg. I append a list of Dr. Dunikowski's determinations:—MONACTINELLIDÆ, *Opetionella* ? sp., *Reniera* sp., *Scolioraphis* ? sp., *Esperia* sp.; TETRACTINELLIDÆ, *Pachastrella* ? sp., *Stelletta* sp., *Geodia* sp.; HEXACTINELLIDÆ, *Lyssakina*, *Stauractinella* sp., *Hyalostelia* sp.; Dictyonina—*Tremadictyum* sp.; *Craticularia* sp. In England only a few Tetractinellid spicules have hitherto been described from the Liassic deposits. These, erroneously ascribed to a genus of Calci-sponges (*Grantia*) by their discoverer (C. Moore, Q. J. G. S. vol. xxiii. p. 538), have been relegated to their right place by Carter. With regard to Dr. Dunikowski's memoir, I have only further to allude to a certain unfairness by which it is marred:—in the first place, a complete suppression of all reference to work of some earlier authors, while later ones are quoted; and, secondly, the ascription to Dr. Zittel of priority in the discovery that siliceous skeletons have been frequently replaced by carbonate of lime, a priority which he would be the first to disclaim.

canal system with the Hexactinellid *Porocypellia*, the Lithistid *Siphonia*, and an undescribed Renierid sponge. It differs from *Porocypellia* in the imperforate character of its nodes and in the absence of a staurodermal covering.

*EMPLOCA OVATA*, sp. nov. (Plate XX. figs. 1-6.)

The species is founded on two well-preserved specimens, one of which is ovate in form,  $1\frac{3}{8}$  inch high and  $\frac{7}{8}$  inch broad; the other, more cylindrical, also  $1\frac{3}{8}$  inch high, but  $1\frac{1}{4}$  inch in breadth. In both, the incurrent ostia are about  $\frac{1}{50}$  inch in diameter, and the osculum  $\frac{1}{4}$  inch. Both are sessile, a scar near the base indicating the point of attachment. The nearest approach I can find to this form amongst described species is *Scyphia radiata ovalis*, Quenst., from the White Jura ( $\delta$ ) of Heuberge, near Balingen. It also resembles *Scyphia dictyota*, Goldf., from the Jurassic limestone of Streitberg.

*Loc.* Dundry Hill, Bristol.

*Hor.* Upper part of *A. Humphriesianus*-zone.

*Obs.* The simplicity of the skeletal nodes is a character which cannot be mistaken in the thin slices of the sponge which I have examined under the microscope; but the presumed absence of a continuous dermal skeleton rests chiefly on negative evidence. Considering, however, the excellent state of preservation of the specimens which have been examined, one would have certainly expected to find some traces of such a dermal covering if it had originally been present.

*Mineral Characters.* The originally siliceous skeleton, in this as in all the sponges described in this paper, now consists of colourless transparent calcite, except where, as near the surface, it is represented merely by hollow casts or moulds lined with a thin crust of some red ferruginous material. The material filling up the meshes of the skeleton is chiefly calcareous, and evidently owes its origin to a very fine calcareous mud, which has since become converted into stone by a deposition of calcite. The calcite in some places (1) has been evenly distributed throughout the mud, and so produced an apparently homogeneous, finely granular, whitish-grey opaque material; in others (2) it has gathered along certain lines so as to form a network, the minute meshes of which are filled with an opaque granular material like that in (1); finally, in others (3) it has entirely obliterated the original granular character of the mud and brought it into the same crystalline condition as itself; thus patches of colourless calcite are produced. The matrix can be traced continuously from one place, where it is in a condition like that described in (1), through others by which it passes through all stages up to (3), that of complete crystallization. The network formed by the absence of mud or concentration of calcite along certain curved lines, as in (2), has a remarkably organic appearance, simulating in some cases Hexactinellid structure so closely as almost to lead astray the observer, the more so that it is frequently in direct continuation with the calcitic replacement of genuine Hexacti-



nellid structure, and so resembles the minute secondary rete which so commonly proceeds from the main fibres of many Dictyonine Hexactinellids. Its occurrence, however, in places where a sponge-skeleton certainly was never present, the wide variation and excessive minuteness of the size of the meshes, and their frequently quite irregular form, all show that we have here to do with a purely inorganic structure; and its explanation is probably to be sought in the segregation of the fine granules of the original calcareous mud about innumerable centres, by which pathways freer from sediment were left, forming a network to be subsequently filled in with calcite. In some places small nodules of white opaque porous silica occur in the matrix. The porosity of this silica is so great that on adding balsam it becomes almost instantly transparent; one can then discern in it a few hollow spaces, lined with a thin film of red oxide of iron, representing casts of the Dictyonine network of the sponge; while more abundantly present are crystals of colourless calcite, similar in character to those which project into it on all sides from the surrounding matrix. One may hence infer that the siliceous nodules are of later growth than the calcitic infilling of the sponge. In connexion with the occurrence of silica it is interesting to note that, corresponding with the replacement of the originally siliceous sponges of Dundry Hill by calcite, we find the opposite replacement to have taken place in the corals of the same deposit, which now sometimes exist as siliceous pseudomorphs: silica is also not uncommon as an infilling material of the associated Foraminifera.

The smaller canals of the sponge, both excurrent and incurrent, are generally traversed axially by a thin thread of calcite, the rest of the canal being filled up with consolidated calcareous mud\*. In describing the *Siphonice* of the Blackdown Greensand I mentioned a similar thread (Q. J. G. S. vol. xxxiii. p. 814), but in this case consisting of silica, and separated by an empty space from the adjoining skeleton. It was conjectured that this thread had been produced from colloidal silica which originally filled the whole of the canal from side to side, but subsequently, on undergoing solidification, shrank to its present dimensions. Since, however, in other sponges, we now find precisely similar threads, but consisting of calcite, which, unlike silica, is not known to originate from a colloidal state, recourse must be had to a different mode of explanation, and the following may be suggested. In some sponges—e.g. *Thenea Wallichii*—the walls of the canals in the living state are formed by a considerable thickness of gelatinous connective tissue, from which the body-spicules are absent, these occurring immediately about the exterior of this gelatinous tissue. If such a sponge should, soon after death, become covered up by fine calcareous mud, it is quite conceivable that the entrance of solid particles of foreign material might be prevented for a time by the presence of an investing skin

\* Quenstedt describes similar threads in the superficial canals, now exposed as shallow grooves, in *S. radiata* (v. Petrefact. Deutschlands, part i. Bd. v. p. 251, pl. cxxvi. fig. 60 z).

and other soft tissues; on the other hand, this would not prevent the entrance of mineral solutions, which, penetrating the interior, might deposit in the vacant canals calcite or silica, as the case might be. Subsequently the organic matter would be dissipated by decomposition, and the fine calcareous mud, no longer excluded, would be able to insinuate itself into every space left vacant by the disappearance of organic matter, and so to fill up the cavity which would intervene between the thread of calcite or other mineral which had been deposited in a canal and the walls of the surrounding skeleton. Thus the problematical threads of our fossil sponges may be regarded as representing the original cavities of the canals; while the consolidated mud or empty space, as the case may be, has taken the place of once existing gelatinous connective tissue. How far this, which is the only explanation I can suggest, is the true one, it is hard to say. One difficulty on the face of it is the rapidity which it seems to require in the rate of deposition of the minerals now forming the axial threads; but till we know more about the durability of certain organic tissues, and the rapidity with which mineral deposition takes place in shallow warm seas, this objection cannot be regarded as a fatal one.

The last constituent of the matrix of this sponge which remains to be mentioned is hæmatite, which occurs dispersed through certain patches of calcite in minute blood-red globules like those described in my paper on the Silurian District of Rhymney (Q. J. G. S. vol. xxxv. p. 504).

#### MASTODICTYUM, gen. nov.

A branching, leaf-like expansion, bearing on the upper surface numerous mamillary processes, or teat-like individuals, resembling diminutive *Emploca*. Each is perforated axially by a cylindrical canal, extending nearly to the base, and opening above in an apical oscule with a sharply defined circular margin. Incurrent ostia are dispersed at about equal distances over the exterior, and the incurrent and smaller excurrent canals run through the walls at right angles to the surface, alternating with each other. Skeleton Euretoid; dermal skeleton absent.

M. WHIDBORN, sp. nov. (Plate XX. figs. 7-9.)

The single specimen on which this species is founded is a fan-like expansion, 3 inches long by 4 inches wide, with mamillæ about  $\frac{3}{4}$  inch high rising from it. The walls of the mamillæ are about  $\frac{1}{8}$  inch thick, the single osculum to each from  $\frac{1}{8}$  to  $\frac{1}{4}$  inch in diameter; the incurrent ostia are from  $\frac{1}{60}$  to  $\frac{1}{45}$  inch in diameter.

Loc. Burton Bradstock.

Hor. Upper part of *A. Parkinsoni*-zone.

*Mineral Characters.* The description given for the previous species, *Emploca ovata*, as regards the characters of the skeleton and infilling material, will apply equally well here, except in respect to a few details, such as the presence of silica in *Emploca*, which does not occur in this sponge. In this, however, and most of the succeeding

specimens, some portions of the parent rock are to be found, either filling in the central tube and the spaces between the papillæ or adherent to the foliaceous base. It consists of a matrix of consolidated calcareous mud, or calcite, which forms a mosaic of minute, ill-defined crystals. Some parts of the matrix are stained a deep reddish brown by iron oxide, while in places rhombohedra of a deep brown colour externally, and apparently consisting of iron carbonate, are strewn through it. Everywhere also remains of calcareous organisms abound in it: Foraminifera, perforate, imperforate, and arenaceous; Encrinite and Asterid joints, Urchin-spines, fragments of Polyzoa, Catagmid sponge-structure, and molluscan shells, together with occasional Entomostraca; grains of siliceous sand, on the other hand, appear to be entirely absent.

#### COSCINOPORIDÆ.

LEPTOPHRAGMA FRAGILE, sp. nov. (Plate XX. figs. 10, 11, 11 a.)

A thin plate, averaging  $\frac{1}{7}$  inch in thickness, bearing on one face circular excurrent ostia,  $\frac{1}{50}$  inch in diameter, arranged, not quincuncially, but in longitudinal and transverse rows, giving to the intervening tissue a square reticulate appearance. On the opposite face incurrent ostia, similarly arranged, but alternating with the excurrent ostia, and concealed by an irregular overgrowth of skeletal network. Incurrent and excurrent canals proceed from their respective ostia at right angles across the sponge-wall, and terminate cæcally. Skeleton Euretoid; distance between the imperforate nodes  $\frac{1}{200} - \frac{1}{150}$  inch: a good illustration is given by Zittel (Neues Jahrbuch für Mineralogie &c., 1877, Taf. ii. fig. 1). The specimens from which this description is taken are evidently fragments of some much larger sponge, which probably had a more or less vasiform shape. They agree in all recognizable characters with *Textispongia foliata*, as described by Quenstedt (Petrefact. p. 64, tab. 117. fig. 7), from the White Jura ( $\beta$ ), over the Fucoid Bank, under Muhlheim, on the Danube, and possibly belong to that species. I have hesitated, however, to adopt Quenstedt's name, because as yet I have only seen figures and no specimens of his sponge, and more particularly because these figures do not include a magnified representation of the skeletal network, without which certainty is impossible.

*Loc.* Burton Bradstock.

*Hor.* Upper part of the *A. Parkinsoni*-zone

#### MÆANDROSPONGIDÆ.

##### PLECTOSPYRIS, gen. nov.

Labyrinthic sponge, formed by winding dichotomizing anastomosing tubes. Skeleton Euretoid.

*Plectospyris* closely resembles *Plocoseyphia*, differing from it in having the skeletal nodes imperforate, not Myliusian.

PLECTOSPYRIS ELEGANS. (Plate XX. figs. 12-14.)

Anastomosing tubes small,  $\frac{1}{4} - \frac{1}{3}$  inch in diameter, wall  $\frac{1}{10}$  inch

thick, internal cavity  $\frac{1}{8}$  inch diameter. Incurrent ostia circular, dispersed at about equal distances over the exterior,  $\frac{1}{60}$ — $\frac{1}{45}$  inch in diameter; the excurrent ostia lie in longitudinal grooves, separated by intervening ridges, on the internal surface of the sponge-tube.

**PLECTOSPYRIS MAJOR.** (Plate XX. figs. 15 & 16.)

Tubes larger than in the preceding species,  $\frac{1}{2}$  inch wide, wall  $\frac{1}{8}$  inch thick, central cavity from  $\frac{1}{8}$   $\frac{1}{4}$  to inch in diameter.

*Loc.* Burton Bradstock.

*Hor.* Upper part of the *A. Parkinsoni*-zone.

The preceding five sponges (*Emploca ovata*, *Mastodictyum Whidborni*, *Leptophragma fragile*, *Plectospyris elegans* and *P. major*) do not differ in any noticeable respect so far as the character of the skeletal network is concerned, and the distinctions between them depend wholly on the various habits of growth and differences in the canal-system. It would be a quite natural arrangement to place them all together among the Euretidae; but, on the whole, it seems to me better at present to refer them to different groups, according to the classification of Zittel.

#### VENTRICULITIDÆ.

##### CALATHISCUS, gen. nov.

A hollow horn-shaped sponge, with a somewhat wide central cavity extending nearly the whole length. Incurrent ostia on the outer surface more or less circular, thickly but irregularly dispersed; excurrent ostia on the inner surface irregular in shape and distribution, markedly larger than the incurrent ostia. Incurrent and excurrent canals forming tortuous branching cavities, interdigitating with each other in the thickness of the walls, reminding one of the canal-system in *Dactylocalyx*. Skeleton a very irregular network, some of the nodes perforate, others imperforate, seldom if ever regularly octahedral.

**CALATHISCUS VARIOLATUS, sp. nov.** (Plate XXI. figs. 17–20.)

The most complete specimen is an irregular vasiform sponge, bent from side to side alternately, and irregularly constricted and swollen at intervals, the swellings or transverse ridgings apparently marking stages of arrested longitudinal growth. It measures 7 inches in length, and 1.5 inch in breadth at the distal end. The walls are  $\frac{1}{4}$  inch thick, the incurrent ostia from  $\frac{1}{36}$  to  $\frac{1}{16}$  inch in diameter, and the excurrent ostia from  $\frac{1}{14}$  to  $\frac{1}{8}$  inch in diameter. The proximal end is not quite complete, and there is no evidence to show whether the sponge was rooted or otherwise attached.

*Loc.* Burton Bradstock.

*Hor.* Upper part of the *A. Parkinsoni*-zone.

*Obs.* The skeletal nodes are not regularly octahedral, as in the Ventriculitidæ generally; but the general characters of the sponge ally it more closely with that family than with any other.



## LITHISTIDÆ.

## RHIZOMORINA.

PLATYCHONIA ELEGANS, sp. nov. (Plate XXI. figs. 22-25.)

Sponge a thin, irregularly undulating plate, with an irregularly curved margin, growing out into lobes which sometimes overlap. Upper surface irregularly ridged and dimpled, ridges occasionally growing up into angular lobes, smooth; lower surface rough, but less dimpled. Thickness of plate  $\frac{1}{4}$  inch, becoming less towards the rounded margin; in the specimen from which the description is taken the length and breadth of the plate are 5 inches and 4 inches respectively. Canal-system absent. Skeleton apparently consisting chiefly of Rhizomorine elements, often arranged in groups forming fibres; but Tetracladine forms are frequently present.

*Loc.* Burton Bradstock.

*Hor.* Upper part of the *A. Parkinsoni*-zone.

*Obs.* The skeletal elements are not very well preserved, so that they do not as a rule appear sharply defined from the surrounding matrix, and thus their tubercular and Rhizomorine character may be more apparent than real, the result merely of subsequent changes. Where they occur exceptionally well defined, they almost always present a quadriradiate outline (triradiate in section), with smooth, almost cylindrical rays, terminating, either immediately or after once bifurcating, in an irregular mass of calcite, which represents the interlocked ends of a number of conjoined elements. From this one is tempted to infer that the sponge rightly belongs to the Tetracladina; but since the distinction between this family and the Rhizomorina rests rather on the presence of Rhizomorine than the absence of Tetracladine elements, I have, though with some doubt, referred it to the latter; and I have been the more readily led to this assignment because Prof. Zittel has similarly referred to the Rhizomorina sponges so precisely similar in all their characters to that under consideration, that, without quite positive evidence to the contrary, I would not venture on a different determination, which would, moreover, involve the institution of a new genus.

## INCERTÆ SEDIS.

The following sponges belong to Zittel's Pharetrones. Their fibres, so far as they exhibit structure, all present us with tri- and quadriradiate spicules, many of large size, their rays being 0.01 inch long and 0.001 in diameter; besides these, smaller spicules of undetermined character are present. I have devoted much time and attention to the study of these sponges without arriving at any positive conclusion regarding their true affinities. They may be allies of *Tricentrium*, or *Tetractinellidæ*, forming a passage between the *Choristidæ* and *Lithistidæ*; or, on the other hand, they may very possibly be, as Prof. Zittel maintains, genuine *Calcspongiæ*. Further research alone can decide. No further light is thrown on the matter by their mineral state: like the undoubted *Lithistid* and

Hexactinellid sponges which occur with them, their skeleton now consists of crystalline carbonate of lime.

*PERONELLA METABRONNII*, sp. nov. (Plate XXI. figs. 26 & 27.)

Sponge of variable form, elongate cylindrical, conical, or obconic; simple, or bearing a second individual budded off laterally. Central or gastric cavity extending a variable distance towards the base, sometimes nearly the whole, sometimes only half way. Thickness of walls variable, often equal to about half the diameter of the central cavity. A measurement taken midway between base and summit gave in one instance 0.1 inch as the thickness of the wall, and 0.2 inch as the diameter of the cavity. In some the wall diminishes in thickness upwards towards the oscule, which is in the centre of the summit; in others, on the contrary, it increases in this direction: in the latter case a measurement gave  $\frac{1}{12}$  inch as the diameter of the oscule and the same as the thickness of the wall; in the former 0.24 inch for the diameter of the oscule and 0.03 inch for the thickness of wall. The sponge is attached at the base, which sometimes grows out into a thick foot.

Skeleton an irregular Lithistid-like network, composed of fibres from 0.005 to 0.01 inch diameter, consisting of large quadriradiate and triradiate spicules, with rays from 0.005 to 0.01 inch long and 0.0005 to 0.001 inch in diameter. On the gastral face of the sponge-wall and in its plane the fibres become flatter and thicker, and the meshes are reduced to oval foramina; on the exterior no change is apparent, and an epitheca has not yet been observed. Besides the central cavity, and a tendency to the formation of lacunar spaces in the skeleton, at right angles to the sponge-wall, no canal-system is present.

The specimens from which the above characters are taken are very similar in macroscopic character to *Spongites Bronnii* of the White Jura, as figured by Quenstedt (Petrefact. Taf. cxxiv. figs. 1-15), but present certain (possibly accidental) differences, such as the absence of an epitheca and of longitudinal ridges on the gastral surface, which render it desirable to distinguish them by a different specific name. Our fig. 26 is similar to Quenstedt's fig. 1, plate cxxiv., representing his *S. Bronnii gemellus*. Our other specimens may be mostly matched by one or other of the seven figures (figs. 6-9 and 13-15) by which Quenstedt illustrates the species *S. Bronnii*.

*Loc.* Burton Bradstock.

*Hor.* *A. Parkinsoni*-zone.

*PERONELLA REPENS*, sp. nov. (Plate XXI. fig. 31.)

Sponge consisting of slender pipe-like individuals, which proceed as branches from a thicker procumbent stem, and subsequently remain free or unite laterally by anastomosis, terminating by rounded ends, in the centre of each of which is a circular oscule. The oscule is the open mouth of a cylindrical axial cavity, which extends continuously throughout the sponge. The diameter of the branches is 0.13 inch, of the central cavity 0.043 inch. Skeleton

an irregular network of fibres, from 0·005 to 0·01 inch in diameter; the fibres become flattened and thickened in the plane of the gastral surface, and thus give a sharp definition to the central cavity; a thin epitheca covers the sponge externally. No other signs of a canal-system besides the central cavity are present.

*Loc.* Hampton Down.

*Hor.* Great Oolite.

*LIMNOREA PYGMÆA*, sp. nov. (Plate XXI. figs. 29 & 30.)

Sponge consisting of small teat-like individuals, 0·18 to 0·23 inch in diameter at the base, 0·25 inch high, growing from a common base, which is overgrown below by a thick concentrically wrinkled epitheca; attached by a very short thick peduncle. At the summit of each mamillary individual is a small circular oscule, 0·08 inch in diameter, from which a cylindrical tube descends vertically for a considerable distance; no radiate canals are visible on the exterior. Skeleton an irregular network of small fibres, 0·0025 to 0·005 inch in diameter, and thus much finer than those of the preceding species; the meshes of the network are also correspondingly smaller.

As some of the characters of this species remain undetermined, its generic position must be regarded as provisional.

*Loc.* Hampton Down.

*Hor.* Great Oolite.

#### *THAMNONEMA*, gen. nov.

Sponge globular, without a central cavity. Skeleton a network of fibres, having, as seen from the exterior, the following disposition:—from a common origin in the centre of the base three fibres radiate in three directions, making equal angles with each other; each soon bifurcates, and the fibres resulting break up at their distal ends into an irregular network of smaller fibres, which extends meridionally up to the summit, uniting with the adjoining fibres along its whole length. The fibre over the base curiously simulates the form of one of the bifurcate ternate spicules of the Tetractinellidæ. The summit is occupied by a looser network (*i.e.* with larger meshes) than the sides. The sides are ridged and furrowed meridionally, the furrows looking like exposed radiate canals; the open meshes of the summit have the appearance of a number of small oscules.

The distinction of this genus depends on the curious arrangement of the fibre at the base, and its subsequent division to form a reticulate fibre, characters which, so far as I am aware, are unique among the Spongiæ.

*THAMNONEMA PISIFORME*, sp. nov. (Plate XXI. fig. 28.)

Sponge globular, flattened at the summit, free,  $\frac{1}{5}$  inch high and  $\frac{1}{5}$  inch broad. Primary fibre of the base 0·014 inch in diameter, secondary fibre 0·007 to 0·01 inch; fibres of lateral network 0·003 to 0·007 inch in diameter.

*Loc.* Hampton Down.

*Hor.* Great Oolite.

**MYRMECIUM DEPRESSUM, sp. nov.***Spongites liassicus*, Quenst. (?).

Sponge small, disciform, with rounded edges, 0.25 inch broad, 0.1 inch thick. Upper surface porous, radiately grooved. Canal-system: central oscule absent, apparently represented by a number of small circular holes or oscules around the centre of the summit; excurrent canals represented by the radiate grooves of the upper surface, and by tubes which descend from the oscules obliquely into the interior; incurrent tubes descending obliquely downwards from circular openings which lie on the ridges between the radiate grooves. Base covered by a thin epitheca, ending in a sharp peripheral edge against the main skeleton. Skeleton an irregular network of fibres, from about 0.002 to 0.004 inch in diameter.

*Loc.* Hampton Down.*Hor.* Great Oolite.

This sponge is almost precisely similar, so far as one can judge from macroscopic characters, to *Spongites liasicus*, Quenst. (Petrefact. pl. cxxxi. fig. 43, p. 343), which, as Quenstedt points out, very nearly approaches *S. semicinctus semiglobus*, Quenst. It differs from *S. rotula*, the type of Zittel's genus *Myrmecium*, chiefly in the absence of a single central oscule and excurrent cavity; but as lipogastrism is not necessarily a character of generic importance, I have not thought this difference sufficient to necessitate generic distinction.

**MYRMECIUM BIRETIFORME, Quenst. Petrefact.**

A small specimen of this sponge occurs in the collection: it is 0.36 inch broad and 0.23 high. It appears to be almost a *replica*, as it were, of Quenstedt's fig. 6, pl. cxxvi., representing his *S. rotula biretiformis*.

**GENERAL OBSERVATIONS.**

*Mineral Characters.*—All the specimens described are preserved in precisely the same manner. The replacement of the siliceous skeletons by carbonate of lime is most thorough and complete, so that, as a rule, all fine structure is obliterated and only general form remains. Thus indications of a canal in the fibres of the Hexactinellidæ are of rare occurrence, and it is needless to add that none of the minute spicules are preserved. The replacing calcite is clear, transparent, and perfectly crystalline, as though it had been deposited as an infilling of hollow casts; not milky, and markedly different from the crystalline deposit of calcite in the matrix, as is the case with *Stauronema*, where the carbonate of lime seems to have been gradually substituted for the silica of the original fibre.

Considering that the silica displaced from sponge skeletons often reappears as a pseudomorph of associated calcareous structures, it is curious that, if originally calcareous, the associated Pharetrones should none of them show signs of siliceous replacement\*.

\* At the time I wrote my paper on *Catagma*, the weight of evidence appeared



*Correlation with Continental Species.*—In the following table the Inferior-Oolite species here described are correlated with those of Quenstedt from the Jurassic strata of various continental localities:—

*Correlation of Sponges here described with those of Continental Deposits.*

INFERIOR OOLITE, ENGLAND.	JURASSIC, CONTINENTAL.
<i>Emploca ovata</i> .....	<i>Siphonia ovata</i> , White Jura $\delta$ , Heuberge.
<i>Mastodictyum Whidborni</i> .	
<i>Leptophragma fragile</i> .....	<i>Textispongia foliata</i> , White Jura $\beta$ , Muhlheim.
<i>Plectospyris elegans</i> .	
<i>P. major</i> .	
<i>Calathiscus variolatus</i> .	
<i>Platychonia elegans</i> .....	<i>Spongites vagans</i> , White Jura $\delta$ .
<i>Peronella Metabronnii</i> .....	<i>Scyphia Bronnii</i> , White Jura $\epsilon$ .
<i>Myrmecium biretiforme</i> ...	<i>S. biretiformis</i> , White Jura $\delta$ .

From this it appears that of the nine species described from our Inferior Oolite, no less than five are closely allied to, if not, indeed, identical with, species occurring on other higher horizons on the continent.

*Depth at which the Sponges lived.*—The Inferior Oolite is a shelly limestone, generally admitted to have been formed under shallow-water conditions. The character of its molluscan remains and corals, and the presence of oolitic grains, are all in favour of the generally received belief.

The sponges we have described—Hexactinellids, Lithistids, and Pharetrones—all occur associated together in the same deposits, and were all alike inhabitants of shallow water.

From this it follows that the accepted belief in the deep-water character of the ancient Hexactinellids, founded on our incomplete knowledge of their existing bathymetrical distribution, is erroneous; and next, either that the recent sponges of this group will be found to extend into much shallower water than has hitherto been known to be the case, or that the family has in course of time largely changed its habits. The former alternative appears to be the right

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to be in favour of these and similar sponges having had originally a siliceous composition, though at the same time I felt and expressed serious doubts on the point. The more exact information lately afforded us by Dr. Hinde (*Ann. & Mag. Nat. Hist.* ser. 5, vol. x. p. 185) on the structure of their fibre, together with Mr. Carter's announcement of the discovery of a living calcareous sponge displaying a similar structure to that described by Hinde (*Ann. & Mag. Nat. Hist.* Jan. 1883), leads me to suspect that full proof of the affinities of these fossil forms with the Calcispongiæ will not be long delayed.

With regard to *Pharetrospongia*, however, no fresh argument of any weight has been alleged against its having had originally a siliceous composition. Most of Dr. Hinde's arguments on this head have been fully answered on the zoological side by Mr. Carter; and with regard to the mineralogical question raised by Dr. Hinde, I may point out that it overlooks the very heterogeneous origin of the Cambridge fossils, and that *Pharetrospongia* has evidently been exposed to very different mineral conditions from the *Ventriculites* of the deposit; in a word, the Cambridge Greensand is the riddlings of several deposits, and that from which *Pharetrospongia* was derived was of a very different character from that which furnished the *Ventriculites*.

one; for Oscar Schmidt, in his last published work on the Mexican sponges, describes several species of Lithistids and Dictyonine Hexactinellids from a depth of 100 fathoms\*; one of the latter, indeed (*Cystispongia superstes*), dredged off Yucatan, comes from the comparatively shallow water of 18 fathoms. Moreover, after a preliminary examination of the 'Challenger' Tetractinellidæ, I find one species of Lithistid which was obtained from a depth of 18-20 fathoms. If, then, Lithistids and Hexactinellids, at the present day, extend into water only 18 fathoms in depth, it is no longer possible to regard their fossil representatives as indicative of deep-sea conditions.

All that we know of the Inferior-Oolite rocks of England points to their having been deposited in shallow water in proximity to a shore-line; and the particular beds in which the just-described Hexactinellids and Lithistids occur bear every stamp of a shallow-water origin: they are impure limestones and shelly breccias, sometimes false-bedded and sometimes oolitic in structure. The molluscan fauna also appears not to be that of a deep sea; and the genus *Litorina* points even to shore-conditions.

That which chiefly conditions the existence of Lithistid and Hexactinellid sponges appears to be uniformity of temperature. This, as all available evidence unites in showing, was an enduring characteristic of our area during Oolitic times.

Through the persistent summer of this period Hexactinellids and Lithistids flourished, along with reef-building corals, in shallow seas, secured from severe seasonal changes of temperature, just as, at the present day, they inhabit the shallow water which washes the shores of coral reefs in the uniform climate of the tropics.

## EXPLANATION OF PLATES XX. & XXI.

### PLATE XX.

Figs. 1-6. *Emploca ovata* (gen. et sp. nov.).

Figs. 1 & 2. The sponge: natural size.

3 & 4. Longitudinal and transverse sections across the canals, showing the axial thread of calcite (*c*), the granular matrix (*m*), and the surrounding skeleton (*s*): ( $\times 22.5$ ).

Fig. 5. Portion of the skeletal network seen in section: ( $\times 45$ ).

6. External surface of the sponge, showing the projecting ends of the external rays of the skeleton: ( $\times 45$ ).

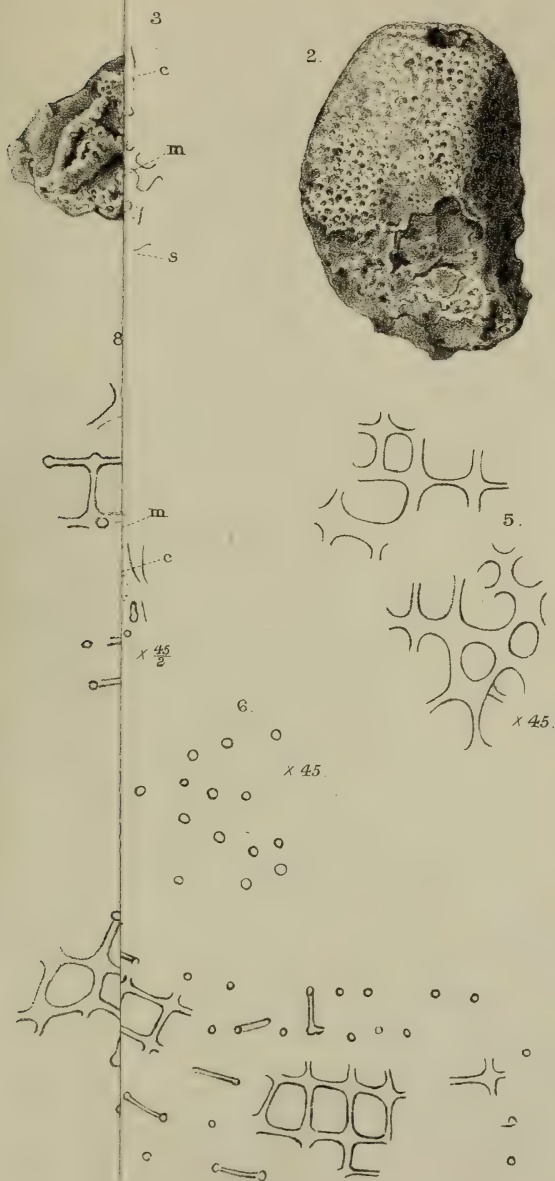
Figs. 7-9. *Mastodictyum Whidborni* (gen. et sp. nov.).

7. A part of the sponge: natural size.

Figs. 8 & 9. The skeletal network shown in section: ( $\times 45$ ).

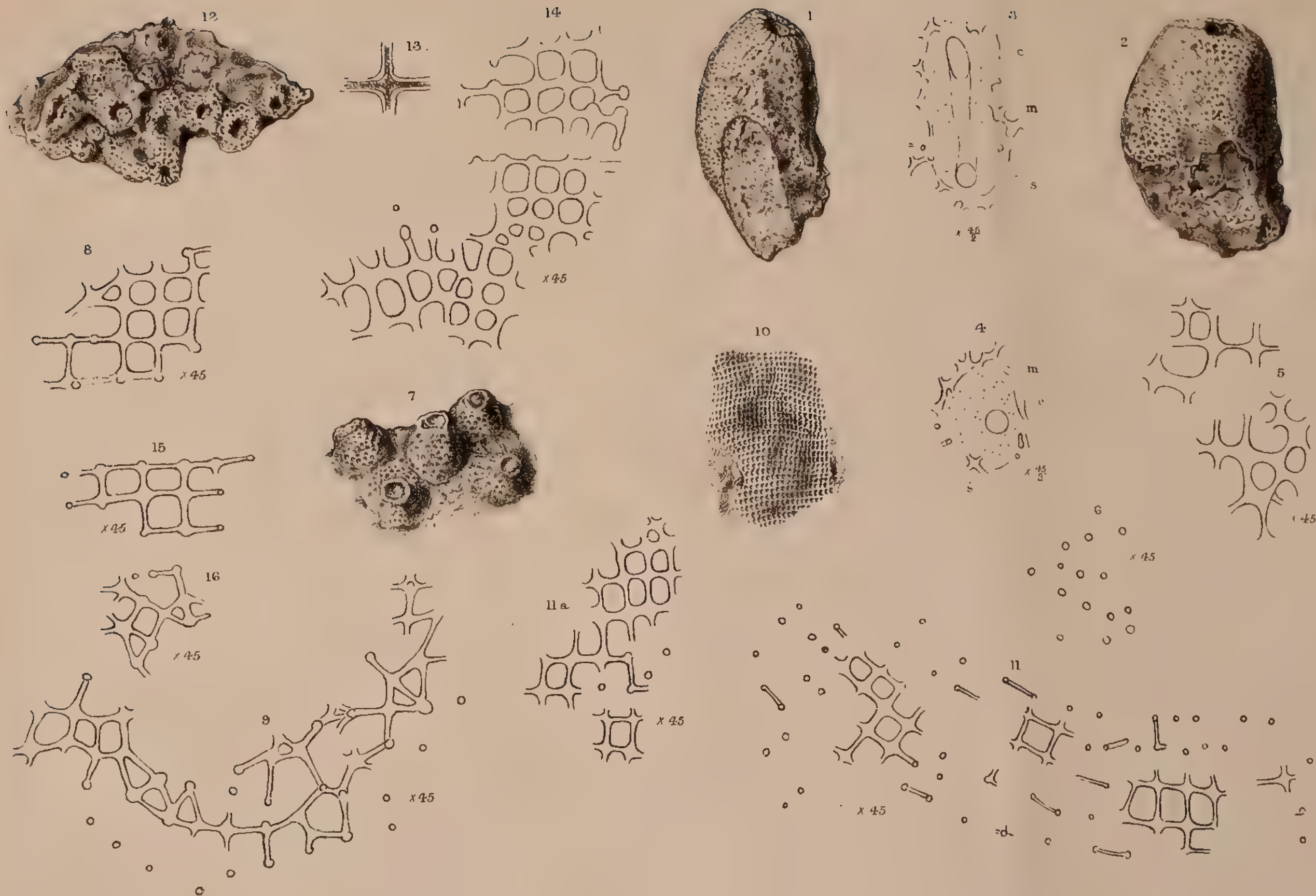
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\* On tabulating O. Schmidt's recorded occurrences of the Dictyonine Hexactinellids, I find 22 cases of species dredged from between 100 and 200 fathoms, 12 from 200 to 300, 4 from 300 to 400, 2 from 400 to 500, 1 from 500 to 600, 2 from 600 to 700, 2 from 700 to 800, 4 from 800 to 900, 1 from 900 to 1000, and 4 from 1000 to 2500 fathoms. Thus these sponges are more frequent between 100 and 300 fathoms than in greater depths, and it may be added that they appear to be most abundant between depths of 100 and 150 fathoms.

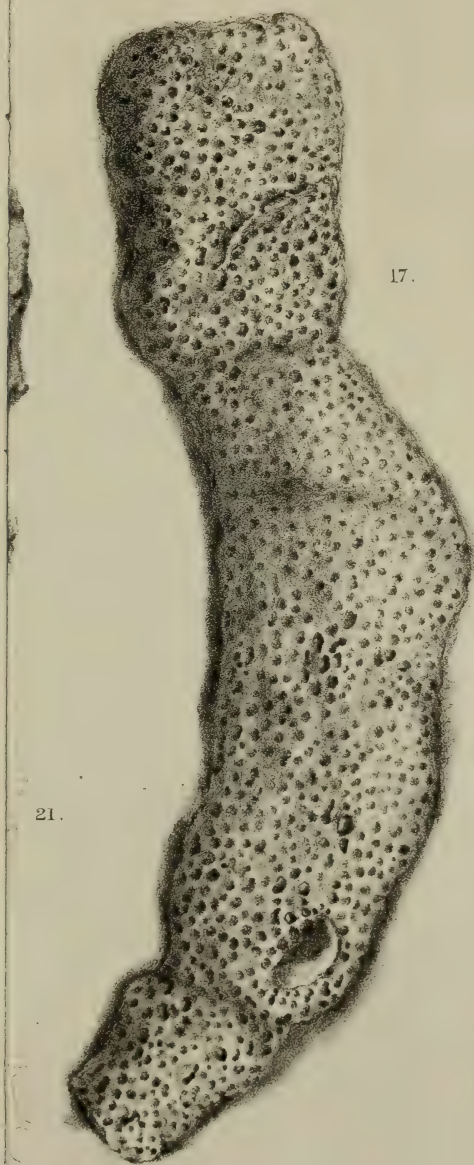




















Figs. 10, 11. *Leptophragma fragile*.

- Fig. 10. Part of the outer surface of the sponge: natural size.  
 11. Transverse section showing skeletal network: ( $\times 45$ ).  
 11a. Tangential section: ( $\times 45$ ).

Figs. 12-14. *Plectospyris elegans* (gen. et spec. nov.).

- Fig. 12. The sponge: natural size.  
 13. A single node of the skeleton, showing the absence of an octahedral lantern.  
 14. Part of the skeleton seen in section: ( $\times 45$ ).

Figs. 15, 16. *Plectospyris major* (sp. nov.).

- Figs. 15, 16. Fragments of the skeleton seen in longitudinal and transverse sections: ( $\times 45$ ).

#### PLATE XXI.

Figs. 17-21. *Calathiscus variolatus* (gen. et sp. nov.).

- Fig. 17. The sponge: nat. size.  
 18. The upper end of the sponge, showing the larger ostia of the interior (*o.i*) and the smaller external ostia (*o.e*): nat. size.  
 19. Portion of the skeleton near the outer surface, showing traces of spicules in the fibre; seen in section: ( $\times 55$ ).  
 20. Fragments of skeleton, seen in section, showing complication of the nodes.  
 21. Outlines of rhombohedral crystals imbedded in the matrix: ( $\times 55$ ).

Figs. 22-25. *Platychonia elegans* (sp. nov.).

22. Sponge: reduced  $\frac{1}{2}$ .  
 Figs. 23 & 24. Portions of the skeleton, in section, with a Tetracladine facies: ( $\times 70$ ).  
 Fig. 25. A skeletal element with a Rhizomorine appearance: ( $\times 70$ ).

Figs. 26, 27. *Peronella Metabronnii* (sp. nov.).

- Figs. 26, 27. Sponge: natural size.

Fig. 28. *Thamnonema pisiforme* (gen. et sp. nov.).

- Fig. 28. *Thamnonema pisiforme*, showing fibres of the base; *c.* centre of origin; *a.* primary, and *b.* secondary fibres: ( $\times 15$ ).

Figs. 29 & 30. *Limnorea pygmæa* (sp. nov.).

- Fig. 29. Sponge: nat. size.  
 30. Base showing concentrically-wrinkled epitheca.

Fig. 31. *Peronella repens* (sp. nov.).

31. Sponge: nat. size.

#### DISCUSSION\*.

The Rev. H. H. WINWOOD said that Mr. Whidborne had not mentioned and seemed to be unacquainted with the collection of Brachiopoda in the Museum at Bath. With regard to the new Brachiopod from Dundry, he supposed that the author was aware of Mr. Moore's labours in this field, and that he had written a paper on Liassic and Oolitic Holothuridæ.

Dr. WOODWARD said it was fortunate Mr. Whidborne had devoted himself to this subject, and as he had considerable experience, he thought good results were likely to follow. The small spicula of a Holothurid described were probably the wheels of *Chirodota*. He would doubtless find a rich field of research in the Bath Museum.

\* Including the Discussion on the preceding paper.

Dr. HINDE expressed his regret that Prof. Sollas was not present to read his own paper, and especially that it was accompanied by neither diagrams nor specimens. Mr. Whidborne was to be congratulated on the discovery of Sponges in a formation where hitherto they had not been noticed, and even on the same horizon on the continent they were not common. The speaker had not found a single *siliceous* Sponge from the Jurassic strata of this country in the Jermyn-Street or British-Museum collections, though on the continent siliceous Sponges were common, especially in the White Jura. The replacement of the siliceous skeleton by calcite was a fact well known to students. A specimen placed in acid would be in part wholly dissolved, while another part would stand out quite clear and perfect. The change certainly had taken place; but the chemistry of it was not yet fully understood. However, there was no doubt that the "organic" silica in sponges was in a very unstable condition. In the Upper Chalk of this country, for instance, only the casts remained. As regards the Pharetrones, which Prof. Sollas regards as *incertæ sedis*, they were regarded by Zittel as allied to calcareous Sponges now existing in shallow seas. This view had been combated by Mr. H. J. Carter and Prof. Sollas. Dr. Steinmann had also considered them not to be calcareous Sponges but allied to Hydrozoa. He (Dr. Hinde) had examined Pharetrones in the British Museum, and discovered in some of them spicules so exactly like those of existing Calcspongïæ, in their form and position, that their alliance with living forms could hardly be disputed. The accuracy of this had now been admitted by Mr. Carter; and Dr. Steinmann had withdrawn his former views respecting them. He did not consider that the occurrence of Hexactinellids with these sponges would vitiate the general evidence for the deep-water habitat of Hexactinellid sponges.

Prof. HUGHES said that further information was wanted as to the circumstances under which this replacement of silica by calcite took place. He asked whether it might have occurred at such a depth as would keep the water, while it was saturated with carbonate of lime and was under great pressure, also at a sufficiently high temperature to carry away the silica in solution. In support of this suggestion he pointed out that where flint is common in the Upper Chalk, there is generally evidence that it was formed after the chalk had been raised and exposed to surface-action such as allows of shrinkage and opening of joints. This is especially shown by the tabular flint along joints oblique to the bedding.

Dr. WOODWARD called attention to some specimens in the British Museum which would be interesting to Professor Hughes, and made some observations on the formation of flint.

The Rev. G. F. WHIDBORNE said that he was acquainted with the labours of Mr. Moore mentioned by Mr. Winwood. Prof. Sollas had intended to be present, and would have brought specimens, but was prevented at the last moment from coming.



30. *On some new or imperfectly known MADREPORARIA from the CORAL RAG and PORTLAND OOLITE of the COUNTIES of WILTS, OXFORD, CAMBRIDGE, and YORK.* By ROBERT F. TOMES, Esq., F.G.S. (Read June 20, 1883.)

## [PLATE XXII.]

INTRODUCTION.—I much regret that in the preparation of the present paper I have not, as on the occasion of my former contribution towards the history of the Madreporaria of the Jurassic formation, had the advantage of repeated personal investigations of the strata from which the specimens were obtained. This expression of regret, however, may perhaps seem unnecessary after the appearance of the very ample and able paper on the Corallian rocks of England by Messrs. Blake and Hudleston\*; but I would observe that as their conclusions were drawn rather from the study of the Mollusca and Echinodermata than from that of the Corals, we are yet in ignorance respecting the exact stratigraphical position of the latter. Consequently it is not by any means certain that the conclusions arrived at by these geologists might not have undergone some modification if the Corals had received more careful examination. Possibly more than one Coralliferous period might have been observed in the Corallian beds, just as more than one has been pointed out in the Inferior Oolite; and as some Madreporarian forms are peculiar to the Coral Rag, it would be interesting to know more fully than we at present do their range in time.

It has always been a matter of some surprise that while the Coral Rag of this country fulfils so completely the conditions of a Coralliferous deposit, and is in so many places crowded with Corals, the number of species should be so small. MM. Milne-Edwards and Haime† give ten genera and fourteen species, and this meagre list has not since been added to, nor has our knowledge of the species been augmented. Although Prof. Duncan has increased the number of Great-Oolite Corals, he has made no addition to our knowledge of those from the overlying Coral Rag; and the very restricted number of species at present known becomes the more remarkable when comparison is made with the numbers which have been described from beds of a corresponding period in France and Germany. It is only necessary to turn to the works of MM. de Fromental, Becker and Milaschewitch, and Quenstedt, to see how comparatively poor in species is our Coral Rag.

Possessed of but little additional information, I must content myself with giving a section of the Coral Rag of one locality, and determining the position of the Madreporaria therein, with alluding to certain other localities, and noting the species therefrom, and

\* Quart. Journ. Geol. Soc. vol. xxxiii. pt. ii. p. 260 (1877).

† Brit. Foss. Cor. pt. ii.

calling attention to some hitherto unrecorded genera and species. One or two of the Coral-Rag species, fully recognized, but not, as I think, well understood, will also be mentioned; and finally some remarks will be offered on the well-known *Isastræa oblonga* of the Portland Oolite.

A large proportion of the Corals from the Inferior Oolite, and a still greater number of those from the Great Oolite, admit of no internal examination, being little better than crystalline casts. The latter, however, often have their external details beautifully retained; while those from the Coral Rag, on the contrary, very rarely exhibit satisfactory external characters, though their internal structure is well preserved and may be successfully studied by means of polished sections or weathered fractures.

The genera now added to the Coral-Rag Madreporaria of England are *Astroccenia*, *Dimorpharæa*, and *Latimæandraræa*, which are already known, and *Crateroseris*, which I now introduce as a new genus.

#### Highworth Section.

	ft. in.	
1. Coral Rag, a true Rag, and exposed on the line of dip from Highworth along the road to Shrivenham, about .....	6 0	<i>Rhabdophyllia Phillipsi</i> , <i>Isastræa explanata</i> ?, <i>Astroccenia major</i> , <i>Thamnastræa concinna</i> , <i>Latimæandraræa corallina</i> .
2. Rubbly limestone of a yellowish or ferruginous colour .....	1 6	<i>Thecosmilia annularis</i> abundant.
3. Fine laminated yellow sand with oolitic grains, mostly in layers, and sometimes indurated.....	5 0	
4. Fine-grained sand, sometimes passing into dark clay, used for brick-making .....	6 0	
5. Coarse oolitic stone in thin layers....	6 6	
6. Ferruginous sandy stone in irregular thin layers .....	0 8	<i>Thecosmilia annularis</i> abundant.
7. Limestone in layers, more or less oolitic .....	3 0	
8. Very dense stone, with a sandy fracture.....	2 0	
9. Soft white sand, sometimes containing calcareous lumps.....	6 0	

The foregoing section is to a certain extent a compiled one, bed No. 1, that is the Coral Rag proper, not being visible in direct connexion with those below, which are exposed in near proximity to the town of Highworth. The Rag is observable at several places on the road from Shrivenham to Highworth, more especially in an extensive but shallow quarry near the road which leads to Warnford Place. In this excavation all the Corals mentioned in this paper as occurring in this district have been found; but as they were chiefly taken either from the heaps of quarried stone, or from the débris left behind, I can only determine their exact position by their appearance and colour, and observe that the large and massive *Thamnastræa* and *Astroccenia* occur in the middle and

upper part of the deposit, and that *Rhabdophyllia Phillipsi* and *Latimæandraræa corallina* are found near to or at the bottom. Another but much smaller opening in the Rag exists on the same level, but much nearer to Highworth; and in the mottled clay in the bottom of this pit I found a prostrate and worn specimen of *Thecosmilia annularis*, in all respects resembling those found in bed No. 2.

In a brickyard on the same road, and quite near to the town, several feet of fine yellow sand passing downward into bluish clay may be seen. This is the third bed of the section.

Passing through Highworth, we come to the brickyard and adjacent quarry, which together furnished the section published by Messrs. Blake and Hudleston, and which presents all the beds below the true Rag which are here alluded to. Bed No. 2 contains *Thecosmilia annularis* in great abundance, all the specimens being much broken up and worn, and consequently prostrate. No other species is associated with them. In the succeeding beds, numbered 3, 4, and 5, there are no traces of Corals; but in No. 6 the same species of *Thecosmilia* is very abundant, and is in the same broken and rubbed state. This bed, as well as those numbered 7, 8, and 9, are well shown in the adjacent and recently excavated road to the Highworth Railway Station, now in course of completion.

Of the exposure of Coral Rag at Headington, which I have visited, I regret that I can say but little, excepting to observe that it contains nearly the same species of Madreporaria as the Coral Rag of Highworth. The following are the species collected by me at that well-known locality:—*Thecosmilia annularis*, *Astrocœnia major*, *Thamnastræa concinna*, and the casts of a branching Coral, which may probably be referred to *Rhabdophyllia Phillipsi*.

It will be seen on referring to the Corals found at Highworth, and comparing them with those from Headington, that the species are identical, and, so far as I am able to judge, identical also with those from Marcham and Cumnor. But the Coral Rag of Cambridgeshire appears to present a different assemblage of species, and the same may be said of the well-known coralline deposits of Steeple Ashton.

### Family *ASTRÆIDÆ*.

#### Subfamily *ASTROCŒNINÆ*.

#### Genus *ASTROCŒNIA*.

#### *ASTROCŒNIA MAJOR*, n. s. Plate XXII. figs. 5 & 7.

The corallum is massive, large, and has an expanded or lenticular form, arising from a rather broad attachment, and sloping outwards and upwards to a rather thin outer margin, the upper surface being a little convex or quite flat.

It consists of rather numerous superimposed layers, without any

appearance of a common wall or epitheca. The calices are large, rudely hexagonal, and internally united by their walls, which are thin but distinct. The columella is about one fourth of the diameter of the calice; it is styliform and prominent. The septa are rather thin, straight, and the primaries and secondaries run into the columella. Those of the third cycle are two thirds the length of the first and second, and those of the fourth are half the length of the third. There is a tendency in the short septa to incline towards or run into the longer ones. All have their sides marked with vertical ridges, which terminate in their margins, and form papillæ which have their greatest diameter across the septa. In almost every instance those of one calice meet and blend with those of other calices at the upper margin of the wall, as in *Clausastræa*. The dissepiments are numerous, thin, and affect a somewhat circular disposition when seen directly from above. In form they are rather like synapticulæ, from which, however, they are quite distinct.

Increase takes place in this species by gemmation on the walls between the calices, just as in *Isastræa*.

The diameter of the calices is about three lines, but sometimes as much as four or four and a half lines.

It occurs, and is not rare, in the Coral Rag at Headington, near Oxford, at Lyneham, Wiltshire, at Highworth, and at Marcham, from all which places I have obtained specimens.

### Family *FUNGIDÆ*.

#### Genus *THAMNASTRÆA*, Le Sauvage.

*THAMNASTRÆA ARACHNOIDES*, Edw. and Haime, Pol. Foss. des Terr. Paléoz. p. 111, 1851; Brit. Foss. Cor. p. 97, 1851.

*Synastræa arachnoides*, Edw. and Haime, Ann. des Sci. Nat. 3<sup>e</sup> ser. t. xii. p. 154, 1850.

Of this well-known species I have lately made an exhaustive examination, with a view to determine, if possible, whether it is a perforate or imperforate Coral, and I am now fully convinced that the septa are strictly imperforate. This will render it necessary that it should be removed from such of the *Thamnastrææ* as have been shown by Milaschewitch to appertain to the Poritidæ\*.

It is probable that the Middle-Lias species, which I have described under the names of *Thamnastræa Etheridgii*, and *T. Walfordi* †, as well as *T. Crickleyensis* and *T. Duncani* ‡, from the Inferior Oolite, have imperforate laminæ. These, with perhaps also *Thamnastræa Manseli* of Prof. Duncan § and some others, will most likely be found to constitute a distinct genus; for whether we

\* Palæontographica, vol. xxi.

† Quart. Journ. Geol. Soc. vol. xxxiv. p. 179, and vol. xxxviii. p. 95.

‡ Ibid. vol. xxxviii. pp. 435 and 436.

§ Suppl. Brit. Foss. Cor. pt. iii. p. 20.



include the perforate *Thamnastrææ* in the Poritidæ or the Fungidæ, we at any rate can scarcely deny that the difference between perforate and imperforate septa is a character of sufficient importance to be regarded as generic.

But there are other peculiarities in the present species which may be mentioned. The first is, that the imperforate septa are connected by true synapticulæ, and not by "oblique cross floors," or tabular synapticulæ; and another is, the tendency to pass from a turbinate to a digitate form, each of the finger-like processes having its surrounding wall and terminal calicular surface. Specimens having the divided form exhibit a distant resemblance to the genus *Epistreptophyllum* of Milaschewitch\*, which genus is, however, characterized by the presence of a single terminal calice, and by the existence of both dissepiments and synapticulæ.

For the present I refrain from further remarks, excepting to repeat my belief in the necessity of separating the imperforate *Thamnastrææ* from those which have their septa pierced, and the pores of which have a distinct arrangement in the different species or groups of species.

*THAMNASTRÆA CONCINNA*, Milne-Edwards and Haime, Brit. Foss. Cor. pt. ii. p. 100. Plate XXII. figs. 1-4.

*Astræa concinna*, Goldf. Petref. Germ. i. p. 64.

Very massive specimens of this common species may be met with at many places. These often exhibit forms so remarkable as to suggest specific or almost generic distinction, and they deserve special notice. After the corallum has attained to a considerable lateral growth, the upper surface throws up numerous conical processes, which have their corallites directed outwards, just as they are in ordinary dendroid *Thamnastrææ*. The corallites by their outward and upward growth increase the diameter as well as the length of the processes, until these, by pressure against each other at their bases, become more or less angular or hexagonal, and are separated only by narrow clefts or sinuses, which by the continued growth of the corallites become ultimately closed inferiorly. When the upper surface of such specimens is afterwards worn down to a convex, or more or less flattened form, what was the centre of the conical processes still retains a certain degree of convexity, owing to the position of the central corallites, which being vertical are more able to resist the wearing process. A shallow depression surrounds this convexity, while the line of union of the outwardly directed corallites proceeding from the several processes, which was previously a narrow cleft, now becomes a prominent ridge. Such specimens, when cut through vertically, present the appearance shown in figure 1 of the Plate accompanying this paper. In these massive and worn specimens the well-developed and styli-form columella becomes very conspicuous (fig. 4), and it is very

\* Palæontographica, vol. xxi. p. 210.

difficult to recognize such specimens as generically identical with those which have no columella.

CRATEROSERIS, n. g.

The corallum is composite, massive, and has a depressed turbate form, and the calicular surface is superior and convex.

There is a common wall, which is naked and costulated. The calices are evenly distributed, round and prominent, but depressed in the middle, and they have a small well-defined fossula. The intercalicular spaces are depressed.

The septa are imperforate, their margins are moniliform, and they are continuous with the septal costæ, which pass from one calice to another without interruption.

Both septa and septal costæ are connected by well-developed synapticulæ.

The method of increase is by gemmation, which takes place in the depressed intervals between the calices at the outer margin of the corallum.

There is very little difference in the form of the calices of this genus and those of *Confusastræa*, to which genus it might be referred, were it not for the wide difference in its internal structure.

CRATEROSERIS FUNGIFORMIS, n. s. Plate XXII. figs. 11-14.

The corallum is flatly turbate, slightly peduncular, and attached by a small surface. The mural costæ are uniform in size, small, and may be traced without interruption from the peduncular region to the calicular margin, over which they pass, and are continuous with the septa of the outer calices. They are rather delicately but obscurely papillated. There is no epitheca.

The calicular surface is more or less convex, and the calices are evenly distributed. They are round, well defined, and prominent, with their middle part depressed and open, and there is a small, round, and well-defined fossula. The intercalicular spaces are depressed.

The septa and the septal costæ are regular, uniform in size throughout, rather thick, very closely placed, and many of them anastomose. All their margins are ornamented with thickly placed tubercles, which are a little flattened, and have their greatest diameter across the septa. There are from thirty-five to forty-three septa, of which from seventeen to twenty reach the fossula; all the others are irregular in length, and many of them run into the larger ones. The cycles are not traceable.

The synapticulæ are well developed and abundant, but they are rather small.

Diameter of the calices from two to three lines; distance from centre to centre of the calices from three to five lines. Height of the corallum two inches, and its greatest diameter three inches and six lines.

Two examples of this coral have come under my observation, both of which were obtained from Steeple Ashton. One of these is in Dr. Wright's collection, and the other is in my own.

## ZOANTHARIA PERFORATA.

## Family PORITIDÆ.

## Subfamily PORITINÆ.

## Genus DIMORPHARÆA, De From.

## DIMORPHARÆA, sp.

I have received several hollow casts of a species of *Dimorpharæa*, from the Coral Rag of Upware, Cambridgeshire, which furnish very good impressions of the calicular surface, and in one of them are some portions of the corallum itself. These show the synapticulæ and the perforations of the septa distinctly, and enable me to determine the genus satisfactorily; but without more perfect specimens I prefer to defer a description of the species for the present. Better preserved examples are desirable for this purpose; but I may observe that it differs from all the *Dimorpharææ* I have seen in having a much greater number of calices. The inner circle, which surrounds the central calice, is only about two lines distant from it, and all the other circles are only that distance from each other. In the circles the calices are very closely placed.

From the number of fragments I have seen I should suppose that it is common at Upware.

## Genus LATIMÆANDRARÆA, De From.

This genus was created by M. de Fromentel in 1856 for some corals from the Corallian of France, for which the name of *Meandraræa* was proposed three years afterwards by M. Etallon\*. The former name has the priority; but I am not aware that it was made known until the publication of M. de Fromentel's valuable little work on fossil corals in 1858-61†. The genus is characterized by not having a visible wall, by the presence of synapticulæ, which structurally resemble those of *Disaræa* and *Microsolena*, by calices which are shallow but distinct, and separated by somewhat elevated but obtuse ridges, confluent septa, a rudimentary columella, and a thin but well-developed epitheca.

By the kindness of M. de Fromentel I have now before me some specimens of *Latimæandraræa corallina*, from the Corallien Inférieur of Champlitte, and with their assistance I have been enabled to determine the generic position of the two species I am about to describe. I must add that in one of these there is very distinct marginal gemmation, and a leaf-like growth, just as in the Astræaceæan genus *Phyllogyra*, to which, excepting for the presence of synapticulæ and distinctly perforate septa, it might be referred.

At page 440 of my communication on the Corals of the Inferior Oolite of Gloucestershire‡, I have observed of some species of the

\* Etud. Paléont. Haut. Jura, p. 123 (1859).

† Etud. Polyp. Foss. p. 247 (1858-61).

‡ Quart. Journ. Geol. Soc. vol. xxxviii. (1882).

genus *Oroseris* that gemmation takes place in the outer prolongations of the septal costæ. This is exactly what also takes place in the genus *Latimæandraræa*, to which genus such species as *Oroseris concentrica* are very closely affined, if, indeed, they should not be placed in it.

LATIMÆANDRARÆA CORALLINA, E. de From. 'Introd. Etud. Polyp. Foss.' p. 247.

A single specimen was found by my friend Mr. T. J. Slatter, F.G.S., amongst the débris of the large quarry between Shrivenham and Highworth\*. It differs from specimens received from M. de Fromental in being more massive in its form, in having the septa and septal costæ thinner, their perforations larger, and the synapiculæ more developed.

Its greatest diameter is three inches six lines, and it has a height of one inch six lines.

LATIMÆANDRARÆA DECORATA, Bean, sp. Plate XXII. figs. 7-10 & 15.

*Meandrina decorata*, Bean, MS.

The corallum is fungiform, and has a thin lobular and somewhat overhanging margin. It is supported on a short peduncle, which has the form of an inverted cone. All the under surface, including the peduncle, has thin, straight, and simple mural costæ, which are not very distinct.

The whole of the upper or calicular surface is formed by the outward growth of leaf-like expansions, originating in a central elongated leaf, and forming calicular furrows, which are short, broad, and open. There are six of them, besides the central or parent leaf; and they have a somewhat radiate arrangement, and, running quite to the outer margin of the corallum, give to it an undulating outline. The greatest number of calices in a furrow is two; but gemmation is seen to be going on actively around the outer margin of the corallum, in the extreme edge of the leaf-like expansions. There is no evidence of gemmation taking place on the central part of the upper surface.

The septa are thin, regular, and uniform in thickness throughout, and when unworn have their margins moniliform. A great many anastomose, especially near the outer boundary of the furrows, where they may be regarded as septal costæ.

There are from twenty to twenty-four septa to each calice, and they all pass into the centre of the visceral cavity, and are attached to the columella, which is irregular both as to size and shape, and has a papillated summit.

The perforations of the septa are not very numerous, and the

\* Since the above was written, I have discovered a young *Thecosmilia* attached to the specimen above mentioned. This must be taken as additional evidence of its occurrence quite at the base of the Coral Rag proper.



sloping tabular synapticulæ resemble those of *Thamnastræa*, but are not much developed\*.

Height of the corallum about nine lines; its greatest diameter one inch seven lines.

A second specimen consists of the peduncular portion only, and has the form of an ill-formed and inverted cone, the margin of which presents a slightly lobular outline.

Both these specimens were sent to me some years since by the late Mr. Bean, of Scarborough, and labelled "*Meandrina decorata*, Bean, Coralline Oolite, Malton."

### *Corals from the Portland Oolite.*

*ISASTRÆA OBLONGA*, Edw. and Haime. Pol. Foss. des Terr. Paléon. p. 103 (1851); Brit. Foss. Cor. p. 73, pl. xii. (1851). Plate XXII. fig. 6.

*Lithostrotion oblongum*, Fleming, Brit. Anim. p. 508 (1828).

Polished specimens of this, the only coral found in the Portland Oolite of this country, are extremely pretty and ornamental objects, and they are to be seen in the lady's drawing-room as well as in the cabinet of the geologist. In such specimens so much difference in internal structure may frequently be observed, as greatly to favour the impression that more than one species have been confounded under the name of *Isastræa oblonga*. But such is not the case, the only real difference being in the state of fossilization; and this difference is so great that the real characters of the species have been overlooked.

All the figures of this Coral given by MM. Edwards and Haime in their 'History of British Fossil Corals,' have been taken from specimens in which the stony tissues of the corallum have given way to and been replaced by a dark-coloured siliceous matter, the very depth of the colour of which has effectually obscured some characteristic details of structure. Their figure 1*f* represents a specimen in which the inner parts of the interseptal loculi, instead of being filled with the usual light-coloured calcareous deposit, remain open, and show the conformation of the septa and the dissepiments very distinctly. But in this figure, as well as in the other on the same plate, the outer parts of the loculi are filled with the same dark siliceous material as the walls with which they are in contact; and as this dark part is not distinguishable from the wall itself, the latter appears to be of twice its natural thickness.

By selecting specimens in which the silicified corallites are less deep in colour, the details of structure are more readily seen, and the wall is observed to be thin, and to be lined within with a considerable quantity of dissepimental tissue, through which the septa

\* For a full description of these peculiarly formed synapticulæ, see the paper by Milaschewitch, in the twenty-first volume of the 'Palæontographica.' When seen from the outside, they exhibit a cuneiform figure, and I have on several occasions described them as cuneiform synapticulæ.

pass and from which they are very clearly distinguishable. This tissue assumes a concentric arrangement, something like a series of rudimentary walls, one within the other, as in *Lithostrction*, in which genus it was placed by its first describer. Sometimes the inner ring of endotheca is more fully developed than the others, simulating an inner wall; but this is not constantly the case, or it would furnish grounds for the creation of a new genus.

There are two species of Corals figured by Reuss from the Cretaceous bed of Gosau, under the names of *Prionastræa Hornesi* and *Isastræa profunda*\*, in which the same kind of dissepimental structure appears as in the present species. Both of these have been subsequently referred to the genus *Isastræa* by MM. Milne-Edwards and Haime†; and the similarity of structure between these Cretaceous species and the Portland one is so considerable, that the latter is most likely quite as nearly affined to the Cretaceous as to the Oolitic forms of *Isastræa*.

In the series of papers which I have prepared on the Madreporaria of the Jurassic formations of this country, and which have been read before this Society, the following new genera have been proposed:—*Tricycloseris*, *Phyllogyra*, *Phylloseris*, *Bathycœnia*, and *Crateroseris*. Eleven other genera, not themselves new, but before unknown in the Jurassic deposits of England, have been made known. They are *Epismilia*, *Donacosmilia*, *Cyathophyllia*, *Confusastræa*, *Chorisastræa*, *Thecoseris*, *Oroseris*, *Dimorpharcea*, *Latimæandraræa*, *Enallohelix*, and *Favia*. *Goniocora*, before unknown, excepting in the Coral Rag, has been found in the Inferior Oolite; and *Astrocœnia* has been added to the list of Great-Oolite and Coral-Rag genera.

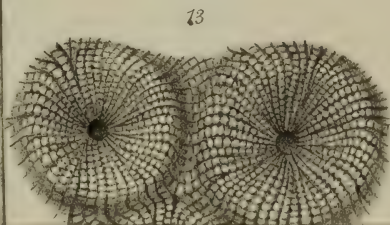
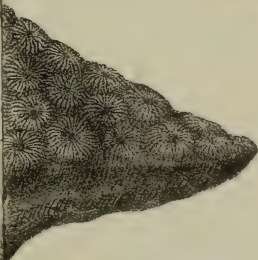
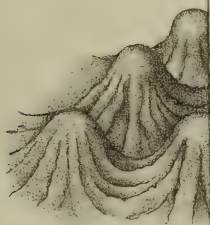
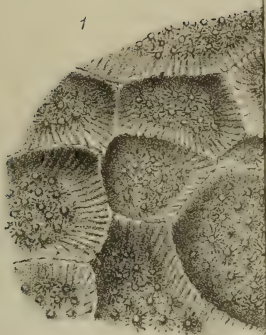
With the present communication ends a series of papers, which have been a long time in hand, and are the results of a protracted and often repeated examination of a very extensive collection of specimens, mostly of my own collecting, and about the locality and stratigraphical position of which there cannot therefore be any uncertainty; but I am sorry to be obliged to add, in conclusion, that I have not myself as yet had the opportunity of collecting in many of the localities from which the Coral-Rag species have been obtained.

#### DESCRIPTION OF PLATE XXII.

- Fig. 1. *Thamnastræa concinna*: a portion of a worn corallum of the natural size, seen from above.  
 2. ———: a vertical section of a tall portion of a corallum, natural size, showing the arrangement of the corallites.  
 3. ———: some calices, magnified.  
 4. ———: some calices much worn, showing the prominent columella, magnified.

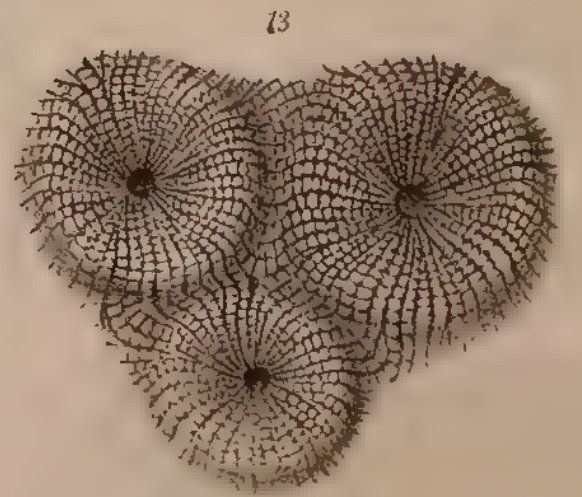
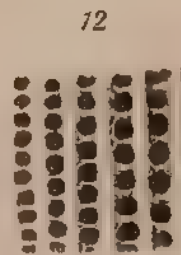
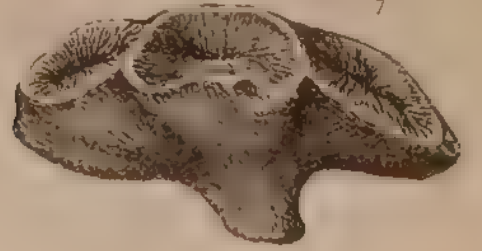
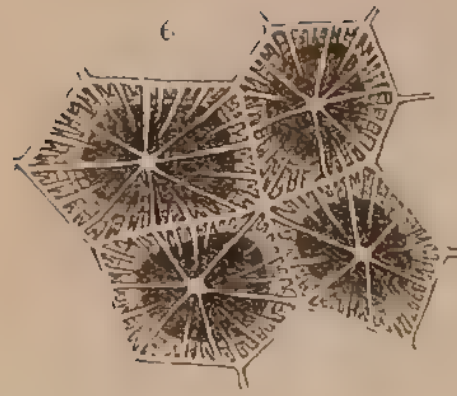
\* Beitr. Kreidesch. Ostalpen. p. 116.

† Hist. Nat. Corall. t. ii. pp. 530 and 534.









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CORALLIAN AND PORTLANDIAN CORALS

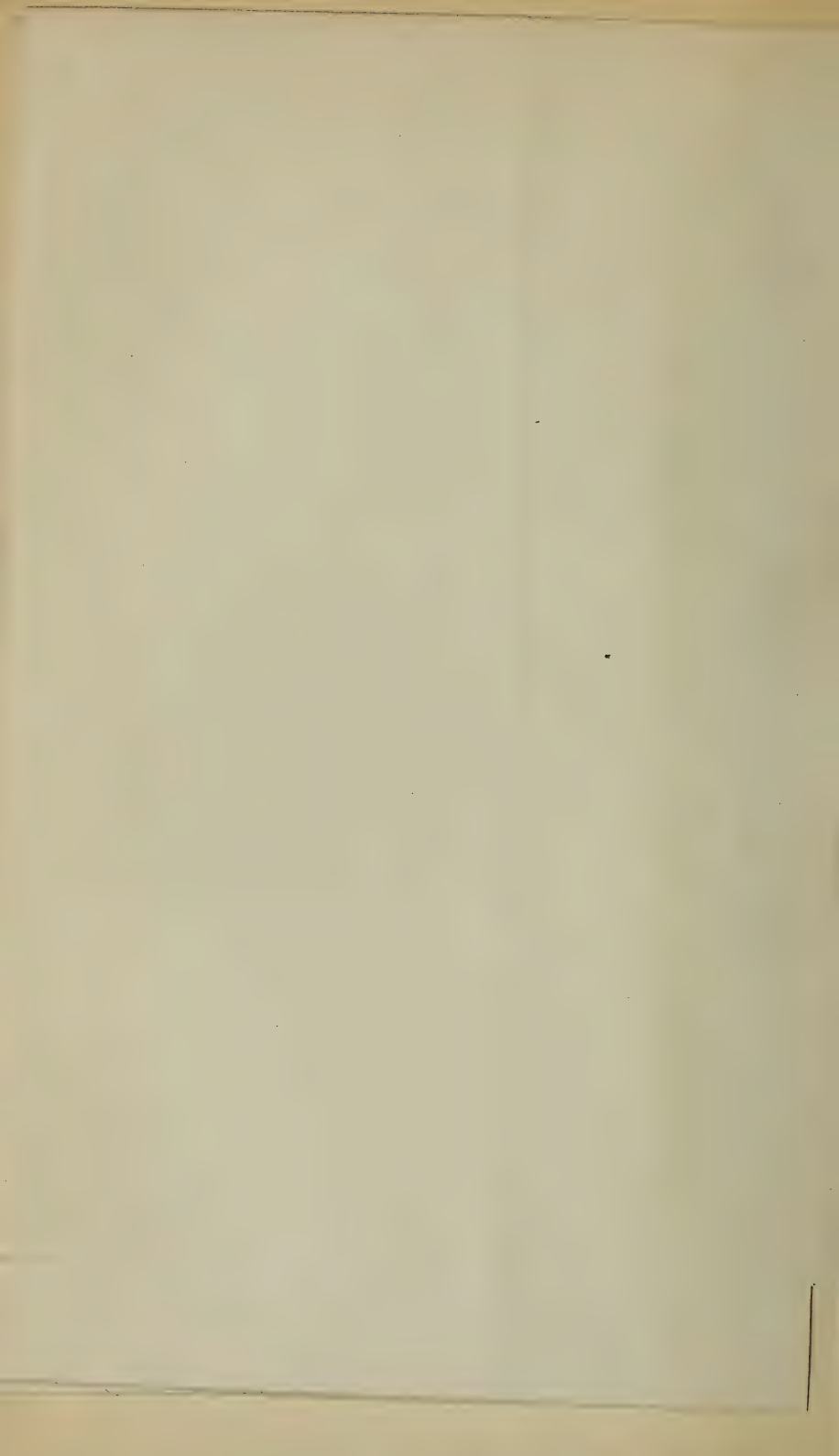


Fig. 5. *Astrocænia major*: some calices a little magnified.

6. *Isastræa oblonga*: some corallites of a polished specimen, magnified, showing the thin walls and interocular dissepiments.
7. *Latimæandraræa decorata*: the corallum, natural size, showing marginal gemmation.
8. ———: natural size, seen from above.
9. ———: magnified portions of the outer margins of some septa, showing their perforations and peculiar synapticulæ.
10. ———: a smaller specimen showing the peduncular portion.
11. *Crateroseris fungiformis*: the corallum, natural size.
12. ———: the weathered outer margins of some septa, showing the synapticulæ.
13. ———: some calices, magnified.
14. ———: some of the mural costæ, magnified.
15. *Latimæandraræa decorata*: a furrow, magnified and showing the columella.
16. *Astrocænia major*: a septum magnified, showing its lateral ornamentation.

31. *On the SECTION at HORDWELL CLIFFS, from the top of the LOWER HEADON to the base of the UPPER BAGSHOT SANDS.* By the late E. B. TAWNEY, Esq., M.A., and H. KEEPING, Esq., of the Woodwardian Museum. (Read June 20, 1883.)

(Communicated by the Rev. Osmond Fisher, M.A., F.G.S.)

THE Hordwell cliffs have been more or less cursorily examined by Webster, Lyell, and Searles Wood, and they were described some time ago by Dr. T. Wright\*. Nevertheless the beds do not seem to be so well known to geologists as the interest of their fauna demands. The cause may perhaps be that observers have of late years failed to find many of the extinct Ruminants which in former times were the especial feature of the freshwater beds at Hordwell. The description of these deposits by the late Marchioness of Hastings† contains the best information concerning the exact beds in which the vertebrate remains were found.

Last autumn we measured the section bed by bed, and the results are here laid down (p. 567). We have adopted the graphical method as an aid, because it alone enables an observer to identify with facility and without loss of time any bed mentioned in the letterpress, and to compare it with the exposure in the cliff. The cliffs in no one spot offer an escarpment where the beds are so accessible that they could be measured vertically from base to summit. Our method has therefore been to measure as much as could be conveniently effected at one place, and then move the position of observation horizontally. Of course, owing to variation in the thickness of beds when followed horizontally, any pretension to minute accuracy is altogether precluded. Absolute accuracy is not feasible in geological sections, nor is it necessary. If the measurements give approximate results for the whole thickness, and preserve roughly the comparative proportions between the individual beds, that will usually be sufficient. It is certainly so here, where there is no great change in the fauna to record. It was desirable, however, to obtain the details as precisely as possible, because our object was to study the distribution of the fossils, the lithological changes being altogether subordinate to this end. The present table will, we hope, serve as an aid, not only to our description but to the valuable work recorded by the Marchioness of Hastings.

We have affixed numbers to the different beds, in order that they may be found at once in the letterpress description, which contains such details as there was no room for in the section. The limits between the beds are of course arbitrary. Probably no two persons working separately would select exactly the same divisions, or group the smaller alternations of sediments in exactly the same way.

We have collated the beds in the Marchioness's description with our own, and quote largely from her work, as it has never been

\* Proc. Cotteswold Club, vol. i. pp. 120-130, and Ann. Nat. Hist. ser. 2, vol. vii. pp. 433-446.

† Bull. Soc. Géol. France, sér. 2, tom. ix. pp. 141-203 (1852).



translated into English. It is indeed fortunate that she has so carefully preserved the information for us relating to the beds which have yielded the vertebrate remains.

The senior of the writers was then acting as her collector. He lived for a great part of his life close to Hordwell Cliff, and for four or five years worked regularly on the cliffs, collecting fossils for the Marchioness. Facts relating to the exact spots where the vertebrate and other remains were found were communicated to her, though occasionally she would assist with her presence.

We are particular in making this admission, because there are some statements in her description which the writer cannot reconcile with his memory or with the present state of the cliff.

As far as the limits to which our section extends, we have, though wishing to draw attention chiefly to the freshwater Lower-Headon series, also added measurements of the sands which come in below, the so-called Upper Bagshot Sands of the Geological Survey.

The thickness of the Lower Headon at Hordwell, between Long Mead End and Paddy's Gap, we make to be  $83\frac{1}{2}$  feet. The measurements given by the Marchioness leave a wide margin. If we take her maximum, it is 94 feet 10 inches, while her minimum gives 78 feet. Dr. Wright's numbers added up amount to about 64 feet.

Commencing at the top of the series, the first bed (33) we describe as brownish-green marly clay, fully 3 feet thick; it shows signs of much weathering, and looks almost as if it was calcareous enough to have been a limestone before being subjected to meteoric action; it contains *Paludina lenta*. Its base is brown and carbonaceous for one inch. A lignitic clay.

(32) next below is a *Limnæa*-marl, passing to pale greenish-brown clay; both may be put together at from 1 foot 10 inches to 2 feet. In this marl serpents' vertebræ have been found, while it has abundance of *Limnæa* and *Paludina*.

We consider this *Limnæa*-marl to be probably on the horizon of, and to be the equivalent of, the How-Ledge limestone on the other side of the Solent. It bears a similar relation to the *Unio*-bed, which is one of marked characters, and easily recognizable both in the island and at Hordwell. Indeed, possibly (32) and (33), with the lignitic layer between, represent the 5 feet of purer limestone at How Ledge, with its thin lignitic layer in the middle.

This stratum, comprising (32) and (33), is the highest bed we have seen in the Lower Headon; it forms the top of the Fresh-water series, which is enclosed between the marine Middle Headon and the estuarine Upper Bagshot Sands.

Above it, we have said, is the Middle Headon, the marine bed which formerly yielded so many of the same fossils as characterize the Middle Headon of Colwell Bay and Headon Hill. The bed is not to be seen now, as we have elsewhere remarked\*, nor has it been visible for many years.

The earliest finder of the bed was apparently Mr. H. Higgins, who found the fossils oozing out of the gravelly undercliff or tumbled

\* Quart. Journ. Geol. Soc. vol. xxxvii. p. 107 (1881).

base of the cliff close to the beach. It was next described by Mr. Searles Wood, who gave a list of its fossils, and stated that it extended for 40 yards \*. It was seen at the time referred to by one of the present writers, whose opinion is that it was distinctly not in place, but was forced up out of the undercliff by the pressure of fallen material. It was so rich in fossils that in a few years every bit of it exposed was carried away by fossil-collectors. In order to obtain a clear section of this bed for the Marchioness, a pit was sunk, clearing away the gravel, and exposing it much higher up in the cliff. From this pit were obtained the fossils in the Edwards, the Marchioness's, and the Woodwardian-Museum collections, besides what found their way into numerous private collections. The writer has visited the locality every year since, and is able to state that the true Middle-Headon bed has never been exposed in place in Hordwell Cliff since that date. Apparently the Long-Mead-End shell-bed (Upper Bag-shot) has been by some mistaken for it.

We cannot agree with what the Marchioness of Hastings has written concerning the position of this bed. She has placed 6–8 feet of grey sands above it; and by the lists of fossils which are given, we are able to identify bed No. 1 of her section as our beds (33), (32), and part of (31). Her No. 2, the Middle Headon, is misplaced; it ought to come above (1). It is described as having been 10–12 inches thick, but “now almost entirely effaced, as it has not maintained a horizontal direction.” The statement of Messrs. Edwards and Wood that *Limnæa* and *Planorbis* are found in the bed, was doubted by the Marchioness, she stating that this bed is truly marine. Then follows a statement, “The band above mentioned, as being found at the base † of the first stratum, takes the place of the second stratum after its disappearance, which is peculiar, because its fossils are indubitably freshwater.” This probably means that the *Limnæa*-limestone further west is seen at a slightly higher level than the marine bed was seen at, which proves that it had slipped, and was not in place. In the present state of the cliff even, it is quite easy to see that she has misapprehended the relative position of these top beds.

Dr. T. Wright ‡ has also misplaced the marine bed. He writes:—“This bed was much covered up at its origin and throughout nearly its entire course at the time of my visit [1850], and was only exposed at one place to the extent of about 10 yards.” It is his bed (4), and he places it below the *Unio*-bed, a clear proof that the marine bed was not in place where he saw it, but squeezed out among the tumbled material. He has further involved matters by placing his bed No. 3 also above the marine bed; whereas it is easily identifiable with bed (4) of the Marchioness's section, a bed below both the *Unio*-bed and the marine bed. The present state of the cliff shows his view to be impossible, as all the beds are now exposed; it should

\* Lond. Geol. Journ. No. 1, p. 2 (1846).

† In her later paper in the ‘Philosophical Magazine’ (*loc. cit.* pp. 3 & 4), the Marchioness refers this fossiliferous band to the top of her Stratum 1.—Ed.  
Q. J. G. S.

‡ *Loc. cit.* p. 123.

have been evident that the marine bed occupying a lower level in the undercliff could not have been in place.

We may add that no beds have ever been seen at Hordwell higher than the marine Middle-Headon bed. This agrees with the view taken by the Rev. O. Fisher, who says:—"It will be seen from the above section [of the Hordwell beds, made in 1853] that the calcareous bands of Hordwell, belonging as they do to the first freshwater series above the Barton, must be correlated with the Lower-Headon Limestones, of which the How-Ledge Limestone is the top. They do not represent the Great Upper-Headon Limestone. Any correlation of the beds of Hordwell Cliff with those of Colwell Bay [north-east of How Ledge] will therefore be misleading; the former being below the horizon of the How-Ledge Limestone, and the latter above it." It is at Warden Cliff and Totlands Bay that the correlatives of the Hordwell Series must be sought for. Mr. Fisher adds:—"The stratum on the mainland which corresponds with the Colwell-Bay or Headon-Hill 'Venus-bed' must be sought for at Hordwell above the freshwater series; and it occurs at a place called Rook Cliff, about a mile to the east of Beacon Bunney in a low cliff. It is usually buried under a talus of gravel" (Geol. Mag. Dec. 2, vol ix. p. 139). Prof. Judd, however, remarks that Mr. Fisher identifies the thin limestone band below the marine bed with the How-Ledge Limestone of the Isle of Wight (Quart. Journ. Geol. Soc. vol. xxxviii. p. 474). But it will be seen that we hold similar opinions with Mr. Fisher. It is true that half a mile further east, near Weston-Lane End, freshwater beds are seen; but they are easily recognizable, from their fossils and peculiar lithological character, as the *Unio*-bed, which, as is well known, belongs to the Lower Headon. They are probably brought up by a slight undulation in the beds; there is no doubt at all as to their identification.

We conceive Dr. Wright to be in error in stating that the Upper Freshwater formation exists at Hordwell, though he gives 20 feet thickness for it. On examining his description we find his bed No. (2) to be the *Unio*-bed, which belongs to the Lower Headon. No such bed exists at any locality where the Upper Freshwater has been examined. Dr. Wright's bed No. (1), from its great thickness, we cannot identify; but it may probably be the upper part of the sands of the *Unio*-bed, which is nearly unfossiliferous at top. He has moreover missed the *Limnæa*-limestone, or else made no mention of it.

Searles Wood, in speaking of the remaining portion of cliff to the eastward, says\*:—"I consider [it], more from position than from its organic contents, as the Upper Fresh-water. Indeed I am not acquainted with any species peculiar to this stratum; for I have found all hitherto published as such in the Lower Freshwater at Hordwell." He thus admits the fossil evidence to be opposed to his conclusion respecting the position.

Dr. Wright's first bed of the Lower Headon (Lower Freshwater) No. 5, is our bed (28), identifiable by the *Gyrogonites*. Both Dr. Wright and Searles Wood † agree in considering the Lower Headon

\* *Loc. cit.* p. 3.

† *Loc. cit.* p. 5.



as a purely freshwater deposit; and we believe that any one who carefully examines the beds will come to the same conclusion.

The next group of beds (31) comprehends sands 7 feet 10 inches base, or alternations of purplish grey sands and clays in thin layers; these are extremely fossiliferous towards the lower part, containing *Paludina* in some layers; but most characteristic are the layers of *Melania turritissima*, *Unio Solandri*, and seed-vessels (*Carpolithes*). At the base is a bed full of these little black seeds with *Uniones*. We have called this the "*Unio*-bed." It is recognizable, with the same characters, in Warden Cliff and Headon Hill, where it occupies a similar position in the Lower-Headon Series.

This bed is apparently bed No. 3 of the Marchioness's section, given as 4-5 feet thick; it is mentioned that a specimen of *Potamides* was found in this bed, "but it is rare."

(30) A series of clays 9 feet thick are classed together, for they are not rich enough in fossils to make further division advisable; they consist of pale greenish clay above, marly beds in the centre with *Paludina*, *Limnæa*, and *Unio*, and green clay below.

This corresponds, at any rate in part, to bed (4) of the Marchioness's section; but, since the thicknesses she gives are usually greater than ours, it is not certain that the same grouping has been taken. She mentions small teeth of undeterminable Mammalia, small jaws, and a large calcaneum from this bed.

(29) Lignitic clay, purplish brown in colour, with reeds: 3 inches.

(28) Whity-brown sands, 2 feet 3 inches. The *Chara*-bed occurs at this horizon, forming pale grey sands about 6 inches thick. It is seen near Paddy's Gap, but thins out further west. It is very rich in seeds of *Chara*, *Limnæa longiscata*, *Melania hordeacea*?, and *Cyrena arenaria*.

These (28, 29) are apparently represented by bed (5) of the Marchioness's section, given as 4-6 feet thick; it is said to begin with a very varied band (about 1 inch) of lignite. Then comes grey sand without fossils,  $1\frac{1}{2}$  foot; next grey clay,  $1\frac{1}{2}$  foot; and it terminates with  $1\frac{1}{2}$  foot of sand, containing *Chara*, fragments of *Trionyx*, *Unio*, *Limnæa*, &c. This is the last bed in which *Unio* occurs. The mention of *Chara* shows that the lower boundary agrees with ours. The thickness given by her is scarcely reconcilable with our measurements.

(27) A lignitic band with *Typha*, 3 inches; thin ferruginous and purplish clay with rootlets, 1 foot.

(26) Clay-iron concretions, reddish and argillaceous at the top of  $1\frac{1}{2}$  foot of a whitish marly hard bed.

(25) Pale grey sands, 8 inches.

(24) Concretionary white marl layers, alternating with pale green layers; bright green clay peculiarly spotted, and thin stiff green clays; the whole  $3\frac{1}{2}$  feet.

(23) Lignite band, 1 inch; whity-brown sands,  $1\frac{1}{2}$  foot.

(22) Bright green clay, and hard clayey marl weathering with a conchoidal fracture,  $2\frac{1}{2}$  feet.

(21) Bright green clays with a shelly band; *Limnæa*, *Potamomya plana*, *Paludina lenta*, *Dreissena*: 7 inches.

Nos. 27-21 probably correspond to bed (6) of the Marchioness's



section, said to average from 15 to 20 feet. A one-inch lignite layer runs across the middle of the bed, and it is said to be almost devoid of fossils; everything agrees with our description except the thickness.

(20) Lignite and clay, 8 inches.

(19) Alternating buff and pale greenish sands, 1 foot.

(18) Bright green clay and stiff green clay, 1 foot 9 inches.

These correspond with bed (7) of the Marchioness's section, the mean thickness of which is given as 4-6 feet, which exceeds our measurement.

(17) Pale cream-coloured *Limnæa*-limestone, 3-7 inches, containing several species of *Limnæa* and *Planorbis rotundatus*. It corresponds obviously to bed (8) of the Marchioness's section. Dr. Wright mentions *Chara* seeds as occurring in this bed.

(16) Clay, sometimes lignitic, 1 inch; then stiff greenish clay, 4½ feet, with a thick iron-stone bed in the middle; at the base of these clays the sediments become more sandy, and contain *Potamomya plana*. This corresponds to bed (9) of the Marchioness's section, who, however, as usual, gives a greater thickness to it.

(15) At the top is soft sand, with *Paludina lenta*, *Limnæa caudata*, *Potamomya plana*, *Cyrena arenaria*, *Dreissena*, *Lepidosteus*, and Crocodile; then hard sand of a pale or whitish tint, with plates of Turtles, and bands of *Potamomya plana*; below are whitish-brown sands, with carbonaceous layers and *Potamomya* in bands. The whole, about 7 feet thick, may be called the Crocodile-bed, having been so known to local collectors; the best horizon for Crocodiles is about 5 feet up in this bed.

In the Marchioness's section it is No. 10, given as 8-9 feet, and seeds of *Chara* are mentioned. She also says that it is the only bed, except her No. 3, in which *Potamides* is found"\*. In the Woodwardian Museum there is a *Crocodilus Hastingsiæ* collected by one of us, with several specimens of *Potamides pyrgota* in the matrix among the bones. The Marchioness draws attention to this association. Of mammals, she mentions *Palæotherium*, *Dichobune*, *Hyaenodon*, found in this bed; of reptiles, besides the Crocodile, are *Trionyx Henrici*, *T. Barbaræ*, *T. marginatus*, *T. circumsulcatus*, and *Emys crassus*. Dr. Wright † states that *Palæotherium splenum*, *P. parvum*, *P. annectens*, *Microchærus*, and *Spalacodon* were also found in this bed. He does not state his authority. Searles Wood, in figuring *Microchærus*, does not state in which bed he found it.

(14) Greenish clay, 2 inches; whitish-brown sand, 6 inches; bluish grey clay-band, 1 inch, with *Melanopsis brevis*.

(13) Light greyish-white sands, 6-9 inches: a constant bed. It may be called the Rolled-bone bed, from the abraded state of the remains. Mammalian bones, *Emys*, *Trionyx*, and Crocodile are mentioned by the Marchioness. These last two beds apparently correspond to No. 11 of her section.

\* In her later paper (Phil. Mag. loc. cit. p. 6) the Marchioness considerably modifies this statement, as follows:—"This and strata 5 and 11 are the only beds where the first-mentioned of these shells [*Potamides*] is found, except very sparingly, and stratum 10 is the only one where they are found in abundance."

—Ed. Q. J. G. S.

† Loc. cit. p. 126.

(12) Greenish-grey clay, with rootlets, 3 feet 3 inches. This seems to be No. 12 of the Marchioness's section, which is given as 1-2 feet thick.

(11) Pale purplish-white sand, with rootlets; much carbonaceous matter in this bed.

(10) Carbonaceous clay, with rootlets, 9 inches to  $1\frac{1}{2}$  foot thick, where we measured it east of Long-Mead End. This is the leaf-bed. West of Long-Mead End it thickens out, *i.e.* carbonaceous and lignitic matter invade a greater thickness of the sediments; fully 12 feet of it are seen in one place. To the east, where thin, it has yielded some good leaves; but near Long-Mead End their structure has gone: they look as if they had lain too long in stagnant water. The last two beds seem to correspond with No. 13 of the Marchioness's section, given as 6-8 feet thick. She mentions an associated set of Palæotherioid bones from this bed.

(9) Bluish-grey clay, with a pale sand layer, *Paludina lenta* and rootlets; some ironstone bands also in the sand; after the whity-brown sands follow some bluish-green clays, still with layers of *Paludina lenta*; and it is in these clays and sandy clays with rootlets that the greater number of the mammalian remains have been found. This may be called the Mammal-bed; its thickness is  $12\frac{1}{2}$  feet. We had the good fortune to find the mandible of a *Dichodon* here on our last visit. Mammals, however, have been seldom found of late years.

This is part of No. 15 of the Marchioness's section, the thickness of which is estimated at 20-25 feet; but our beds (8-3) seem also to be included. She states that she obtained from it *Anthracotherium*, *Anoplotherium commune*, *Paloplotherium*, *Trionyx*, *Emys*, sometimes bones of birds &c.; "remains are not common and difficult to extract."

(8) Argillaceous ironstone, 10 inches.

(7) Marl bed, 1 inch, contains serpents' vertebræ, *Paludina*, and *Potamomya*. The Marchioness mentions a bed immediately above the ironstone, with vertebræ of lizards, and teeth of mammals, and fishes, crocodiles, *Trionyx*, and *Emys*. It is a pity that these teeth were not determined at the time. Though the collection is now in the National Museum, Cromwell Road, and can be studied, there is no means of recognizing what bed a tooth or bone comes from unless it be imbedded in matrix. She also notices our bed (7) below the ironstone as containing the same fossils. Both these (7 and 8) form part of bed No. 15 of her section.

(6) Sandy clay, 2 feet 3 inches.

(5) Greenish-grey clay, stained with carbonaceous matter at the top, about 3 feet.

(4) Purplish clay and lignitic bands, 2 feet; the lower part of the clay is light grey in colour.

(3) Blackish-grey clay full of fossils, 8 inches; *Dreissena Brardii*, *Potamomya plana* in great abundance, *Cyrena cycladiformis*, *Cerithium pyrgotum*, and *Melanopsis fusiformis*.

We consider this still a freshwater bed because of the *Dreissena* and *Potamomya*; but in the Marchioness's section she makes the

estuarine series commence at the lignite. The lignites, again, are much more likely to be freshwater, since they contain leaves and rushes, which seem to have been deposited in still and stagnant water.

(2) Pale grey clay, with rootlets, 1 foot.

(1) Lignitic bed, 2 inches. We make this lignite the base of our Freshwater series or Lower Headon. Below commence the Estuarine beds, which have been called "Upper Bagshot Sands" by the Geological Survey. From the time of Searles Wood and Dr. Wright, and their contemporaries, their estuarine character has been recognized.

The total thickness of the freshwater Lower Headon we have here measured as  $83\frac{1}{2}$  feet. In Totland Bay and Headon Hill we estimated the thickness of the same series as 87 feet. At Hordwell there are not so many *Limnæa*-limestones as at Warden Cliff; but the deposits are much richer in vertebrate fossils than in the Isle of Wight, and the Lower beds are much richer in fossils of all sorts than at Headon Hill. Vertebrates have, however, been found in the Lower Headon of Headon Hill: we may refer to the jaw of *Dichodon cuspidatus*, Ow., found by Dr. Wright and described by Prof. Owen\*.

We will now proceed in descending order with the measurements of the individual beds of the Estuarine series. At the commencement they are so rich in fossils that they are worthy of separate mention.

(a) Dark grey to black laminated clay, 10 inches. *Neritina concava*, *Cerithium variable*, *C. pyrgotum*, *Melanopsis fusiformis*, *Dreissena Brardii*, *Cyrena cycladiformis*?

(b) Mottled green and grey sandy clay; the grey portions ramifying in the green in tubular shapes, 1 foot; rich in fossils:—*Oliva Branderi*, *Cer. variable*, *C. pleurotomoides*, *Natica labellata*, *Melania hordeola*, *Melanopsis fusiformis*, *Marginella simplex*, *Cyrena cycladiformis*.

(c) Dark grey to black clay, with grey sand-layers, 1 foot. Fossils abundant—Coprolites, *Melania muricata*, *M. hordeacea*, *Cerithium pyrgotum*, *C. ventricosum*, *Dreissena Brardii*, *Modiola Nystii*.

(d) Grey sandy shell-rock, about 1 foot thick, full of fossils—*Cerithium pleurotomoides* being excessively abundant. Many years ago one of the authors found three turtles in this bed; they were whole when found, but could not be preserved.

These beds (a-d) apparently correspond to the lower part of No. 16. of the Marchioness's section, 4-5 feet. She mentioned that they are generally covered with beach; but the sea having swept the beach away in August 1851, what had not been seen for years was discovered. We may add that we were equally fortunate in August 1882. The crowding of the fossils in places is extraordinary. The beds were measured by us at Long Mead End.

(e) Whity-brown to pale yellow sands, with some ochreous seams; a layer of *Cerithium pleurotomoides* at the base.

(f) Pale grey sand full of *Cerithium pleurotomoides*, ochreous colour

\* Quart. Journ. Geol. Soc. vol. iv. p. 36.

in places. Other fossils in layers are: *Oliva Branderi*, *Psammobia solida*, *Melania hordeacea*, *Cyrena cycladiformis*.

These sands are exceedingly rich in fossils in layers. We have on a former occasion \* given a list of them obtained a little west of the path down to the beach at Long-Mead End; but we had not then the opportunity of seeing these beds so well exposed, which, as we have mentioned, were especially favourably seen this time.

(g) Below is white sand, apparently unfossiliferous; fully 10 feet of it are seen; but this may possibly be somewhat less than its real thickness. Owing to the tumbled material it is not easy to see its base and summit at the same time.

Adding up, we should have a thickness of  $17\frac{1}{2}$  feet for the Upper Bagshot Sands, and  $87\frac{1}{2}$  feet for the freshwater Lower Headon.

The limit between them is, of course, slightly arbitrary, since the marine shells gradually die out, while the freshwater ones, such as *Dreissena*, are occasionally found in the uppermost estuarine beds, where the passage begins. We place the line of division one bed above where we last found *Oliva Branderi*. In the top bed of the estuarine series is occasionally seen a stray *Potamomya* or *Dreissena*; otherwise we should say that there was a definite line at the lignite, dividing the freshwater shells from the estuarine and marine. The *Oliva* is common to the clays below, well seen at Beacon Bunney.

It may be considered a marine inhabitant, and is one of the well-known links connecting the Upper-Bagshot sands with the Barton beds. It is not found higher up in the series.

#### DISCUSSION.

The PRESIDENT spoke of the pains always bestowed by the late Mr. Tawney on his geological work, and invited discussion.

Prof. PRESTWICH remarked upon the few papers that had been published on the Hampshire coast, hence the value of this paper; but it was hardly possible to discuss it without a map or sections, especially as it had necessarily been much abbreviated.

Prof. JUDD said that the paper seemed to be a critical one, and the criticism was rather of the nature of a statement that the authors had not seen what several distinguished observers, such as Mr. F. Edwards, Mr. Searles Wood, Dr. Wright, and others stated they had distinctly seen. He himself had seen a portion of the bed in question. This bed, which had been seen *in situ* by so many observers, we were now asked to believe was only a squeezed-out mass. It was remarkable that one of the authors of this paper had assisted most of the geologists mentioned above, when either he failed to persuade them that his present view was the right one, or his memory had failed him as to what he then thought on the subject. The coast had receded greatly at this point, the beds were very variable, and exact identification of them over wide areas was not possible.

\* Quart. Journ. Geol. Soc. vol. xxxvii. p. 115 (1881).



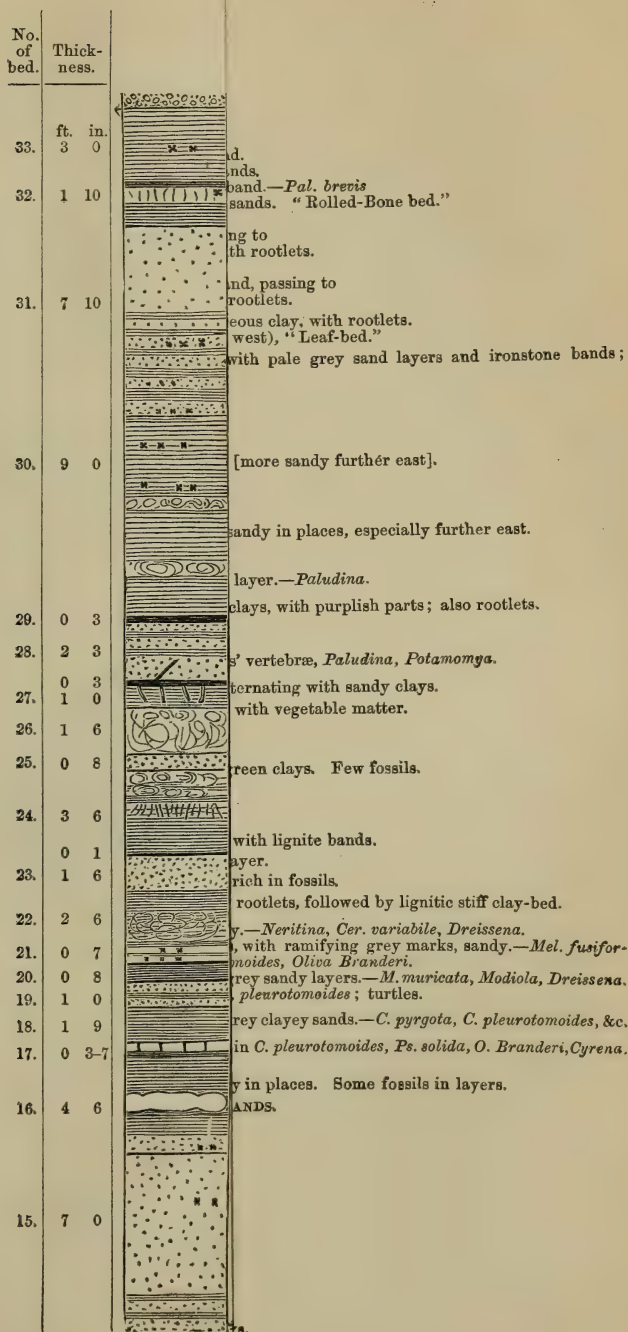
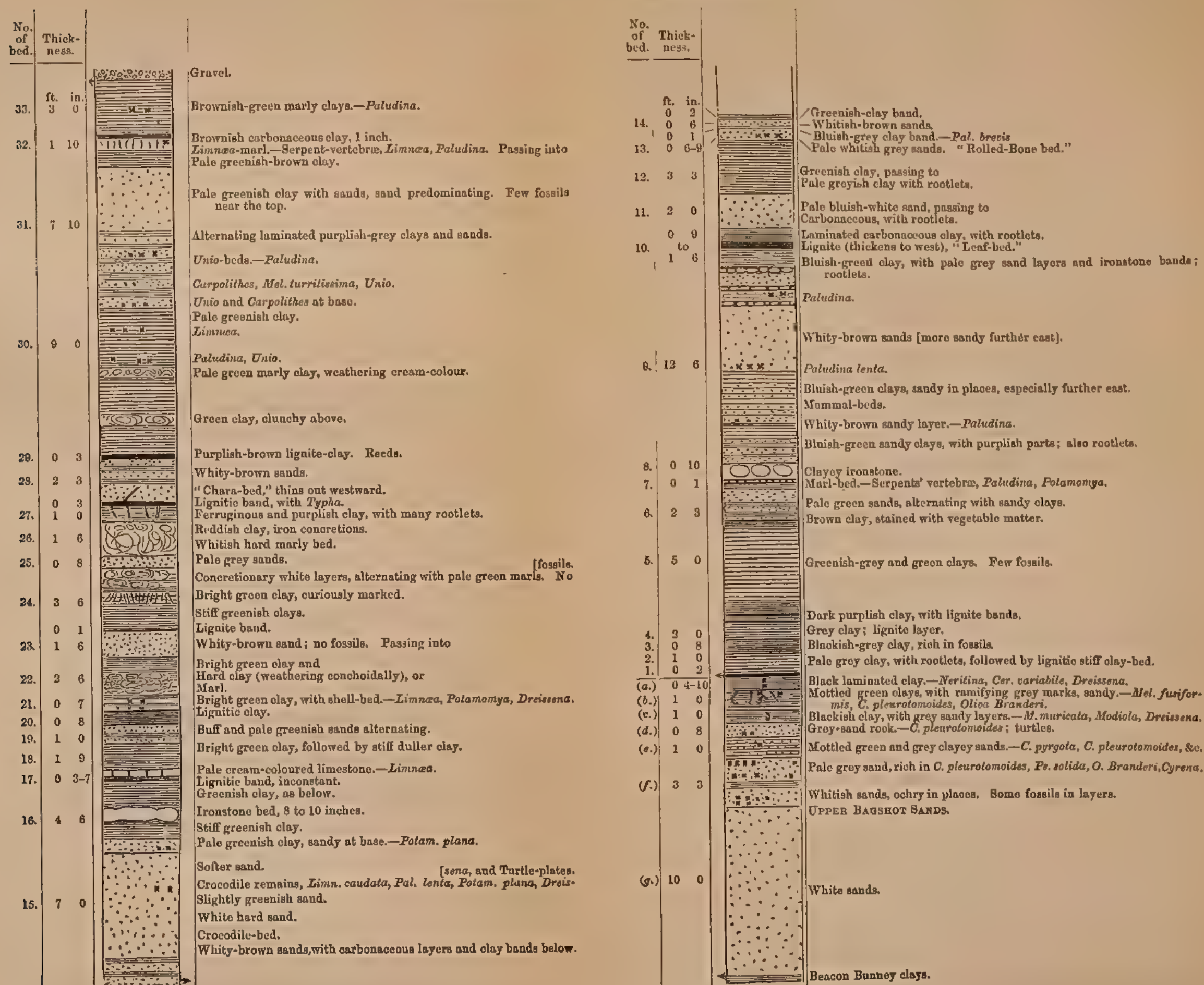
Fig. 1.—*Vertical Sands.* (Scale  $\frac{1}{8}$  inch to a foot.)



Fig. 1.—Vertical Section of Hordwell Cliff from the top of the Lower Headon Beds to the base of the Upper Bagshot Sands. (Scale  $\frac{1}{8}$  inch to a foot.)

(Total thickness of Lower Headon beds 83½ feet.)







32. *On the alleged* EXISTENCE *of* OVIBOS MOSCHATUS *in the* FOREST-BED, *and its* RANGE *in* SPACE *and* TIME. By W. BOYD DAWKINS, Esq., M.A., F.R.S., F.G.S., Professor of Geology and Palæontology in the Victoria University. (Read June 20, 1883.)

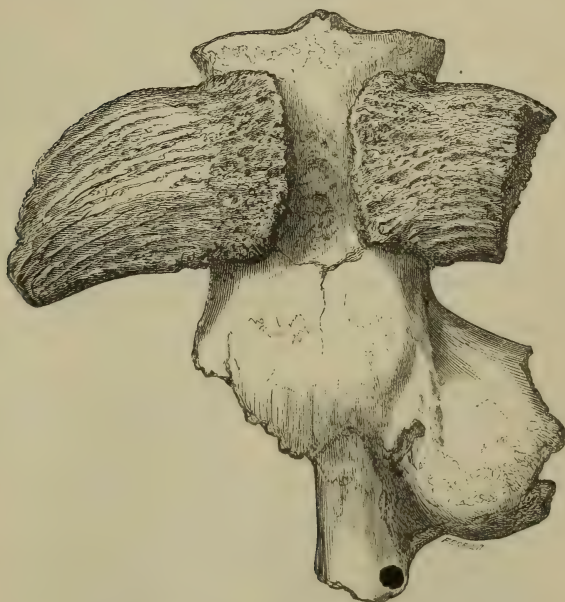
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1. *Introduction.*

THE specimen which forms the subject of the present notice formed part of the collection of the late Rev. F. Buxton, and was sent to me for identification by his brother, Mr. A. F. Buxton, in

*Skull of* Ovibos moschatus (*Forest-bed, Trimmingham*).  
(One fourth natural size.)



April 1883. It was obtained by a fisherman from the Forest-bed of Trimmingham, four miles from Cromer, in Norfolk, and may be

inferred to have been discovered *in situ*, since its edges and processes are sharp and fresh, and the red matrix is still adherent in places. Had it been a waif and stray on the beach, it would have been water-washed and more or less abraded, as is invariably the case with beach-specimens cast up by the waves.

## 2. Description and Identification.

It consists of the posterior half of the upper surface of the skull (see figure), comprising part of the occipital, the whole of the parietals and frontals with the basal portion of the two horn-cores, the posterior half of the left orbit, the lacrymals, and fragments of the maxillaries. The measurements of the various parts are given in the accompanying table in the first column in inches and tenths.

*Table of Comparative Measurements of Skulls of Musk-Sheep.*

	Fossil.					Living.		
	Trimingham.	Male, Crayford.	Male, Maidenhead.	Male, Freshford.	Female, Freshford.	Male, Brit. Mus.	Female, Coll. Surg.	Male, Richardson.
Nuchal crest to fronto-nasal suture .....	9.5	...	...	...	...	11.2	7.6	13.8
Frontal width at parieto-frontal suture .....	4.5							
Frontal width in front of horn-cores .....	3.4							
Extent of orbits from median suture of frontals .....	4.8	4.4	...	...	...	4.4	3.4	5.4
Extent of orbit beyond facial plane of maxillary .....	2.0	...	...	...	...	1.7	1.9	2.5
Space between horn-cores ...	1.5	.65	.5	.4	1.0			
Basal circumference of horn-cores .....	11.0	17.6	13.1	14.0	15.0	14.5		
Length of horn-cores .....	5.0							

On comparing the skull from Trimingham with the fossil skulls from various deposits in Britain, which have been described in my monograph\* on *Ovibos moschatus*, as well as with the recent skulls in the British Museum and the College of Surgeons, from the Arctic regions, it is at once obvious that it belongs to the same series and is specifically identical with the living Musk-Sheep. I have further compared it with the *Bootherium* of Leidy, the remarkable extinct *Ovibos* of the Pleistocene strata of North America, and find that it has no affinities in that direction. It is, in fine, a fragment of a large skull belonging to an adult female, with the orbital ring

\* *Ovibos moschatus*, Pal. Soc. vol. xxv.

projecting slightly further outwards than in the few specimens with which it has been compared; and its only importance lies in the fact of its having been obtained from the Forest-bed, from strata earlier in point of time than any in which it has hitherto been found.

### 3. *Range in North America, Northern Asia, and continental Europe.*

Since the publication of the memoir on *Ovibos moschatus*, published by the Palæontographical Society in 1872, several discoveries have been made which render it desirable to give an outline of the range of the animal in space and time up to the knowledge of to-day. The animal is, as is well known, now only found in the mossy treeless districts bordering on the Arctic Ocean in North America and Greenland, and apparently does not range, even in the winter, further to the south than the latitude of  $59^{\circ}$ ; nor does it range further to the west than the valley of the river Mackenzie. In the Pleistocene age, however, it extended far beyond these narrow limits. The remains obtained by Captains Beechey and Kellett in the frozen loams, sands, and gravels of Eschscholtz Bay prove that then it lived on the banks of the streams opening on Behring's Straits, along with the elk, bison, reindeer, horse, and mammoth. It is represented by a closely allied form in the Pleistocene strata of the United States, the *Ovibos cavifrons* (male), *bombifrons* (female) (= *Bootherium* of Leidy), found at Big-bone Lick, in Kentucky, along with the remains of the reindeer, Virginian deer, elk, bison, horse, mammoth, *Mastodon*, *Megalonyx*, and *Mylodon*, and in other localities in the water-shed of the Mississippi as far south as Arkansas.

On the western side of Behring's Straits the remains of the musk-sheep are found throughout the area of the Siberian tundras, and side by side with the mammoth and woolly rhinoceros, and in Northern Germany in association with the same animals, and in various river-deposits and caves in France, generally along with these animals and sometimes with flint implements, and the remains of *Elephas antiquus*, the cave-hyæna, and the bear. *Ovibos moschatus* therefore ranged in the Pleistocene age over an enormous tract in the Old World, over the Siberian steppes, over Russia in Europe, and Northern Germany, and as far to the south west as the Pyrenees.

It has not been found south of the Alps or west of the Pyrenees, which formed barriers to the migration of the northern group of Asiatic animals in those times.

### 4. *Present in Britain in Late Pleistocene Age.*

The musk-sheep has been recorded in Britain from the following localities\*:—in 1855 a fragment of a skull of a male was obtained by the Rev. Charles Kingsley and Sir John Lubbock from the low-level gravel of the Thames near Maidenhead, in which occur also the remains of the mammoth. To Sir John Lubbock also we are indebted

\* See *Ovibos moschatus*, *op. cit.* chap. iv.

for the second find of skull of a male in the fluviatile gravel of Green Street Green near Bromley in Kent, associated with the remains of a bison. A third case is the discovery of portions of male and female skulls by Mr. Charles Moore in the gravels of the Avon at Freshford, near Bath, along with the mammoth, bison, horse, and reindeer.

The animal has also been discovered in the gravels of the valley of the Severn at Barnwood, near Gloucester, by Mr. Lucy, in association with the mammoth and woolly rhinoceros; and in those of the Wiley at Fisherton, near Salisbury, along with the same group of animals and the stag, wild boar, pouched marmot, lemming, wolf, lion, and striped hyæna. In all these cases the presence of the Northern group of mammalia and of the mammoth and woolly rhinoceros, coupled with the absence of survivors from the Pliocene fauna, make the time of its sojourn in Britain to be late Pleistocene; nor can there be any doubt as to the animal having inhabited the valley of the Severn in postglacial times, since the gravel\* composed of the neighbouring Oolites, in which its remains occur, rests upon the older postglacial gravel, which was formed by the break-up of glacial deposits with erratics by the streams. In this case the evidence is perfect that the animal was in Britain long after the retreat of the ice from the valley of the Severn, and after the emergence of that low-lying district from beneath the waves of the Glacial sea.

##### 5. *Present in Britain in Mid and Early Pleistocene Ages.*

The discovery of the skull of a fine old male in 1866 by myself and Mr. Flaxman Spurrell in the Lower Brick-earth of the Thames Valley at Crayford proved that the musk-sheep was present in an older fauna than the above, a fauna from which the arctic mammalia with this solitary exception are absent, while the Pliocene species are represented by *Rhinoceros megarhinus*.

Since that time a few isolated teeth have been discovered at Erith in the same strata by Messrs. Cheadle and Woodward. It was therefore living in the valley of the Thames during that Mid Pleistocene division, according to my classification. The relation of this deposit to the Boulder-clays further to the north seems to me to be defined by the fact that it underlies the confused strata known under the name of "Trail," in which the action of either ice or snow is obvious in the transport of angular masses of soft Woolwich Clays at Erith, and that this trail on the side north of the Thames at Ilford is composed of materials in part derived from the Boulder-clays of the district, even if it be not Boulder-clay rearranged *in situ*. The Lower Brick-earths, too, differ from the other fluviatile deposits in the Thames valley in the fact that they contain no erratics, and therefore must have been formed before the erratics were brought into the area of the Thames valley by the ice, and before the streams had

\* Lucy, "The Gravels of the Severn, Avon, and Evenlode," Cotteswold Club, April 7, 1869, p. 8. The oolite-gravel of Barnwood is seen at Kingsholm overlying the gravel with erratics.



begun to attack the Boulder-clays, and to deposit their débris in the gravel bands of the Thames valley. From these two considerations I am inclined to hold that these deposits are preglacial, in the sense of being before the period of the Boulder-clay in the Thames valley.

#### 6. *Present in Britain in Early Pleistocene Ages.*

Whatever doubts, however, may be held concerning the relation of the Lower Brick-earth of the Thames valley to the Boulder-clays, there can be none regarding the Forest-bed and associated estuarine and freshwater series; and consequently the skull found at Trimingham proves that the musk-sheep was in the valley of the North Sea before the Boulder-clay, and extends its range to the early preglacial stage of the Pleistocene period, when the living mammalia came in force into Europe and began to supplant the Pliocene species.

#### 7. *The Overlap of Pliocene and Pleistocene Mammal-faunas in the Forest-bed.*

In the Forest-bed Pliocene and Pleistocene species are so mingled together as to prove that the mammal-faunas overlapped in that area of Norfolk and Suffolk. To what extent this took place may be seen from the following list brought down to the knowledge of to-day.

#### *Mammalia of the Forest-bed and Fluvio-marine Series.*

##### Survivals from Pliocene. Living species.—1.

*Hippopotamus amphibius.*

##### Survivals from the Pliocene. Extinct species.—11.

<i>Machairodus</i>	<i>Rhinoceros etruscus, Falc.</i>
<i>Cervus Polignacus, Rob.</i>	— <i>megarhinus, Christ.</i>
— <i>dicranios, Nesti, = C. Sedgwickii, Falc.</i>	<i>Equus Stenonis, Cocchi.</i>
— <i>Carnutorum *, Laug.</i>	<i>Elephas meridionalis, Nesti.</i>
— <i>etueriarum ?, Cr. et Job.</i>	<i>Trogontherium Cuvieri, Owen.</i>
	<i>Cervus tetracerus †, Dawk.</i>

##### New Comers. Living species.—21.

<i>Canis lupus, L.</i>	<i>Equus caballus, L.</i>
— <i>vulpes, L.</i>	<i>Castor fiber, L.</i>
<i>Mustela martes, L.</i>	<i>Arvicola glareolus, Schreb.</i>
<i>Hyæna crocuta, var. spelæa.</i>	— <i>amphibius, L.</i>
<i>Gulo luscus, L.</i>	— <i>arvalis, Pal.</i>
<i>Ursus ferox.</i>	— <i>gregalis, Pal.</i>
<i>Sus scrofa, L.</i>	<i>Mus sylvaticus, L.</i>
<i>Ovibos moschatus, Bl.</i>	<i>Talpa europæa, L.</i>
<i>Bos primigenius, C.</i>	<i>Sorex vulgaris, L.</i>
<i>Cervus elaphus, L.</i>	<i>Mygale moschata, Fisch.</i>
— <i>capreolus, L.</i>	

\* After a careful survey of St.-Prest in 1880, and an examination of the fossils in the Ecole des Mines in Paris and of those in the Château de Dampierre, collected by the late Duc de Luynes, I am obliged to assign the stratum with these remains to the late Pliocene instead of the early Pleistocene.

† This specimen is in the Museum of the Geological Survey in Jermyn Street, and was obtained from the freshwater deposit at Runton. The species is also represented by many fragments from the Forest-bed in the collection of Mr. Back-

## New Comers. Extinct species.—6.

Ursus spelæus, <i>Goldf.</i>	Elephas antiquus, <i>Falc.</i>
Cervus verticornis, <i>Dawk.</i>	Arvicola intermedius, <i>Newt.</i>
Elephas primigenius, <i>Bej.</i>	Caprovis Savinii, <i>Newt.*</i>

From the examination of this list it will be seen that out of 39 species, twelve belong to the Pliocene strata of France and Italy, while 27 are to be counted as immigrants and, with three exceptions (*Cervus verticornis*, *Caprovis Savinii*, and *Arvicola intermedius*), as common late Pleistocene forms. It is obvious therefore that the line of division between the Pliocene and Pleistocene must be drawn so as to include the Forest-bed within the latter. The additions made to the fauna by Mr. E. T. Newton and others since the publication of my memoir † on classification in 1872 have confirmed the accuracy of this conclusion, and have further proved that the arctic mammalia were then in the valley of the North Sea. It is not a little strange that the musk-sheep and the glutton, two animals now living side by side in North America, should appear together in Britain. They undoubtedly were driven so far south at this time by the gradual lowering of the temperature, which has left its mark in the Forest-bed strata by the replacement of the cold-temperature trees of the Forest-bed proper by stunted types peculiar to cold climates, and by the appearance of Arctic species such as *Salix polaris* and *Hypnum turgescens* ‡.

## 8. General Conclusions.

The following conclusions may be drawn from the foregoing observations:—First that the Musk-sheep invaded Britain from the continent, along with the rest of the North-Asiatic animals characteristic of the Pleistocene area, before the glacial conditions of climate had set in in the area of the eastern counties; secondly, that it was living in the valley of the Severn after the glacial conditions had disappeared from that area. It most probably arrived at the southern limits of its range on the continent while the cold was at its height in Britain, and swung northwards again as the cold diminished. In other words it may be said to be pre-, inter-, and post-glacial in Europe. Lastly it may be gathered from the large number of living species of mammalia in the Forest-bed that the phenomena summed up under the head of glacial do not form a hard

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house. The species occurs in the Pliocene strata of Auvergne. See Dawkins, "Contributions to the History of the Deer of the European Miocene and Pliocene Strata," Quart. Journ. Geol. Soc. 1878, p. 416.

\* From these lists I have omitted all the doubtful forms and more especially the fragmentary antlers, which await future identification. For an admirable account of the Vertebrates of the Forest-bed, see E. T. Newton, "The Vertebrates of the Forest-bed series," Mem. Geol. Survey, 1882. To the lists hitherto published I have added three forms, the *Ovibos moschatus*, the *Cervus tetraceros*, and the *Hyæna spelæa*, the last of which is in the collection of Mr. Backhouse.

† Quart. Journ. Geol. Soc. Nov. 1872.

‡ Nathorst, in Lyell, 'Antiquity of Man,' 4th edit. p. 262.

and fast barrier between one fauna and another, and cannot be said to define the close of one geological period and the beginning of another.

#### DISCUSSION.

The PRESIDENT called attention to the variation in the skulls of living musk-sheep, connected with sex and age.

Prof. PRESTWICH expressed some doubts as to whether Prof. Dawkins had established satisfactorily the fact that the specimen had come from the Forest-bed. It was found, not in the Forest-bed itself, but at Trimmingham, four miles from Cromer, and where mammalian remains abound from more recent deposits. Hence, he thought that the geological horizon of the fossil was not proved. As regards the occurrence of *Ovibos* in the Thames valley, it was a wide question as to whether the beds at Crayford were Preglacial. For his part he did not see how these could be separated from others at Grays and elsewhere, which were pretty certainly Postglacial.

Mr. J. EVANS said that, in the case of a dredged fossil, strong evidence as to the locality was needed. However, he saw no reason why the animal should not be Preglacial. Still he did not think that the Crayford-bed could be safely regarded as Preglacial. The implements of human origin which had been found there were flakes such as hitherto had not been attributed to the very earliest palæolithic type. At Green Street Green, also, *Ovibos* had been found with implements which seem most probably Postglacial. Man might have migrated with *Ovibos*; but it would be singular if in so long an interval of time there had been no change in his weapons.

Prof. BOYD DAWKINS said the specimen was brought by fishermen to Mr. Buxton. He had no information that it was dredged. From the physical character and the matrix he thought it a Forest-bed specimen. As regards the age of the Crayford deposits, he was unable to agree with the speakers. The Crayford deposits had no erratics; the ordinary gravels of the Thames—at Maidenhead, for instance—had. As regards the supposed interval of time between the Preglacial and Postglacial type of River-drift man, he thought that the wide extent of the type over India, the Mediterranean shores, Europe, and even America, proved a long existence in time. River-drift man probably arrived in Europe prior to the Glacial epoch.

33. NOTES on a COLLECTION of FOSSILS and of ROCK-SPECIMENS from WEST AUSTRALIA, north of the GASCOYNE RIVER. By W. H. HUDLESTON, Esq., M.A., F.G.S. (Read June 6, 1883.)

[PLATE XXIII.]

THIS collection was made by Mr. Forrest, the colonial surveyor, and forwarded by him together with the accompanying map to Sir Charles Nicholson, by whom the specimens were placed in the hands of Dr. Gwyn Jeffreys for determination. Dr. Jeffreys brought the parcel over to the apartments of the Geological Society, and it was suggested that I should undertake to examine and report upon them. Being quite unaware that the whole of the fossils were palæozoic, including several species of Polyzoa and Actinozoa, I somewhat rashly undertook a task which, as regards the palæontology, it would have been impossible for me to have fulfilled, but for the kind assistance of Professor Morris and Mr. Robert Etheridge, junior, to both of whom my acknowledgments and best thanks are due.

It will scarcely be necessary to refer in detail to the literature of Australian geology on the present occasion. A full list of all the works bearing on the subject is to be found in the catalogue by Messrs. Etheridge and Jack, whilst the former gentleman's catalogue of Australian fossils, published at the Cambridge University Press in 1878, is indispensable to any one who takes up this question. There are two works, however, that may be specially mentioned, viz., Strzelecki's 'New South Wales' &c., with notes on the fauna by Lonsdale and Morris, published in 1845, and De Koninck's 'Recherches sur les fossiles paléozoïques de la Nouvelle Galles du Sud,' published in 1876-7. The Quarterly Journal of the Society contains a most important and interesting paper by the late Mr. Daintree on the geology of Queensland\*, together with Mr. Etheridge's valuable appendix on the fossils, chiefly Mollusca. This appendix has been supplemented by a paper read before the Royal Physical Society of Edinburgh, by Mr. R. Etheridge, junior (Feb. 1880), on a collection of fossils, also Mollusca, from the Bowen-river Coal-field in Northern Queensland, and further by the joint paper of Messrs. Nicholson and Etheridge on Palæozoic Corals from Northern Queensland†.

Very little seems to have been written of late years on the subject of West Australia; the latest notice I can find in the Society's Journal is a short paper‡ by Mr. F. T. Gregory communicated in 1861, wherein the author refers to a geological map and sections presented to the Society as far back as 1847§. It thus appears that the Society is already in possession of important information regarding

\* Vol. xxviii, p. 271, with appendix by Etheridge, p. 317.

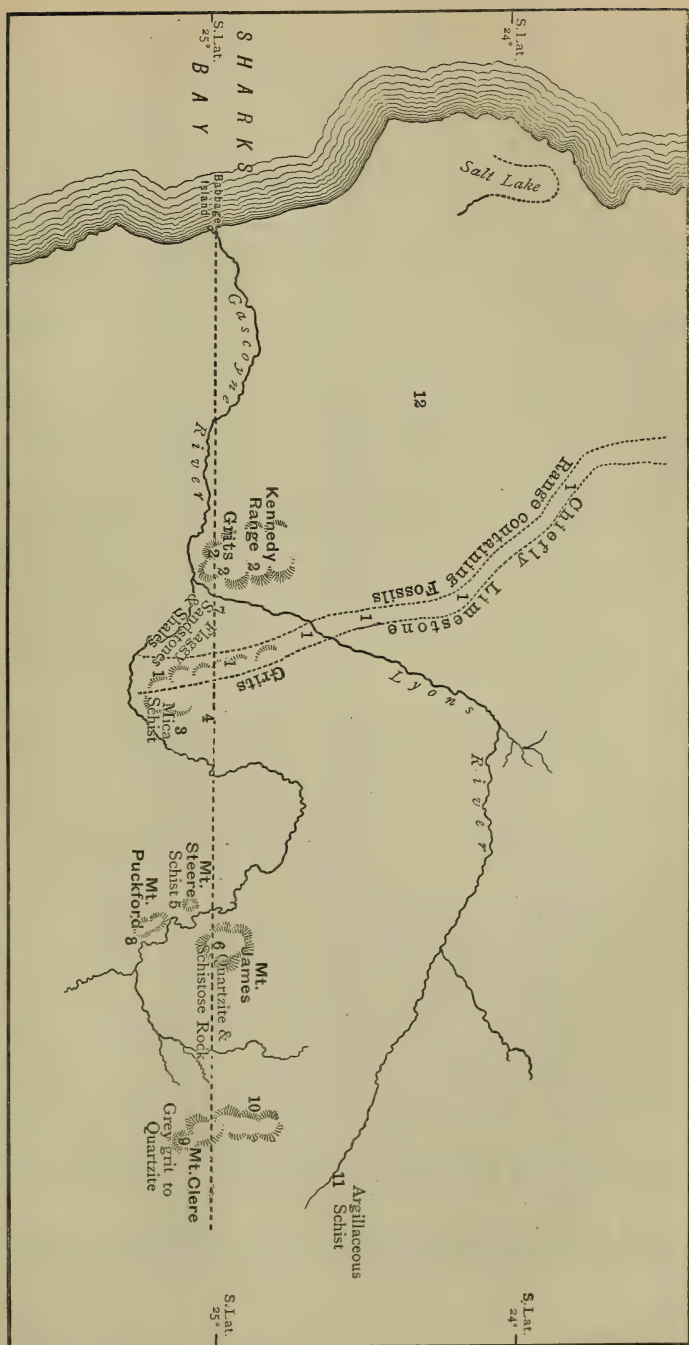
† Ann. & Mag. Nat. Hist. ser. 5, vol. iv. p. 265 *et seq.*

‡ Quart. Journ. Geol. Soc. vol. xvii. p. 475.

§ See Quart. Journ. Geol. Soc. vol. iv. p. 142.



Fig. 1. *Sketch-Map of the basin of the Gascoyne River, West Australia.*  
 (Abridged and reduced from Mr. Forrest's map showing pastoral leases between the Murchison and Ashburton rivers.)



The numbers indicate the positions where the specimens were obtained.  
 The dotted line shows the approximate position of Mr. Gregory's section.

the geology of West Australia as far north as the Gascoyne river in latitude 25° S.

Speaking of the Darling Range and the country to the eastward, Mr. Gregory says that the principal portion of West Australia consists of an undulating table-land of syenitic granite, which has a western face rising abruptly from a plain of small elevation to a height of from 800 to 1200 feet above the level of the sea, gradually ascending, for 200 miles to the eastwards, to 1400 or 1600 feet, and even as high as 2000 feet. Two diagrammatic sections were given, one, about 40 miles in length, in latitude 32° S., where the edge of the syenitic granite is about 20 miles from the coast. The crystalline rock, which in this latitude forms the western edge of the Darling range, is represented as being penetrated by numerous "dykes" of "serpentine," porphyry, and quartz.

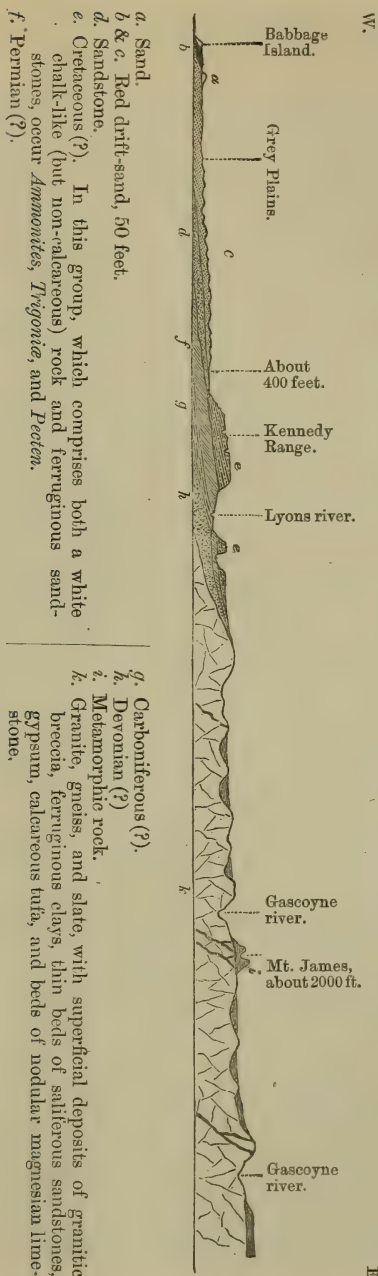
The second section is about 200 miles in length from west to east, and may be said to include the entire valley of the Gascoyne river, in latitude 25° S., from its sources to the sea. From this section we learn that the outcrop of the crystalline rocks in this more northern region is about 90 miles from the coast, instead of 20 miles, as was the case on the more southern parallel, and furthermore that there is no such abrupt rise as occurs immediately to the east of the Swan river, in the higher latitude. On the contrary we learn that about the confluence of the Lyons and Gascoyne rivers, a very considerable thickness of palaeozoic rocks reposes, as it were, on the flanks of the crystalline group, and thus serves to moderate the sharpness of the declivity. Annexed is a copy of Mr. Gregory's second section (fig. 2, p. 585).

The paper and sections by Mr. Gregory must, then, be regarded as having laid the foundation of West Australian geology south of the parallel of the Gascoyne river, and, indeed, fully up to that river, whilst the collecting of Mr. Forrest, the present surveyor, has been limited to the regions upon, and to the north of, the Gascoyne river; as indicated in the map which accompanies this report. Beyond the fact that he has discovered a range, or, more properly speaking perhaps, a sort of continuous outcrop, trending N.N.W. for nearly 150 miles, which has yielded an interesting suite of Carboniferous fossils, there does not seem to have been any noteworthy discovery\*. This fact, however, is in itself one of considerable importance, as it places the existence of a large sweep of Carboniferous rocks beyond the possibility of a doubt; whilst, owing to the poverty of the collection exhibited by Mr. Gregory, which only contained one coral (referred to *Cyathophyllum*), two or three species of *Spirifer* and *Productus*, and a few Encrinital stems brought from the Irwin river along with coal, the age of the coal-bearing beds of that river had even been questioned. Moreover, as will be seen subsequently, the Forrest collection is extremely interesting from a

\* In his letter to Sir Charles Nicholson, dated Perth, Nov. 4, 1882, he speaks of having collected many fossils, some of which he had forwarded to England.

Fig. 2.—*Diagrammatic Section across a part of Western Australia, in lat. 25° 15' S. (Length about 200 miles.)*

From Mr. Gregory's paper in Quart. Journ. Geol. Soc. vol. xvii. p. 477.



palæontological point of view, and affords a further testimony to the extent and importance of the Carboniferous formation on the Australian continent.

*Rock-specimens.*—A few small rock-specimens accompany Mr. Forrest's collection; and as he has been careful to mark the localities on the accompanying map, it would have been possible to make a sort of guess as to the nature of some of the formations even without the aid of Mr. Gregory's section. The specimens collected by Mr. Forrest, being for the most part from the basin of the Gascoyne river, enable us to test, as it were, Mr. Gregory's section, which, on the whole, they seem to confirm.

Subjoined is a brief description of the more important rock-specimens, with references to the localities whose petrology they are intended to illustrate.

The character of *No. 1* may be gathered from the numerous fossils as well as from the small rock-specimen so labelled. We thus arrive at the conclusion that the "Range containing fossils" is, in the main, composed, of a limestone-grit varied by sandstones and flaggy micaceous grits. Some of the fossil casts occur as a ferruginous fine-grained sandstone without lime, and sometimes as a dark hornstone or chert. Some of the *Fenestellæ* occur in a flaggy calcitic limestone which is tolerably pure. The corals also are calcareous, and the interior of the tubes filled with calcite.

*No. 2.* There are three specimens with this label. One is the cast of an *Orthis* in a ferruginous fine-grained sandstone. The others are flaggy, fine-grained, and somewhat micaceous sandstones without a trace of carbonates. On turning to the map, we perceive that these specimens come from the S.E. side of the Kennedy Range, facing the junction of the Lyons and Gascoyne rivers. Thus it is not improbable that here also is a sandstone formation homotaxially Carboniferous. The higher portions of this range are marked as possibly Cretaceous in Mr. Gregory's section.

*No. 7.* This lot comes next according to topographical arrangement. The specimens are derived from the opposite side of the Lyons river; between it, in fact, and the southern prolongation of the "Range containing Fossils." One is a soft, grey, micaceous, flaggy sandstone, and the other a dark grey, micaceous shale, with markings which may be fucoidal. I think that *No. 7* represents the detached summit, immediately east of the Lyons river, marked *e* in Mr. Gregory's section, and according to that section a Cretaceous outlier.

*No. 3* is from the east side of the "Range containing Fossils," between it and the northerly bend of the Gascoyne River, about the position where the crystalline rocks are first shown as coming to the surface in Mr. Gregory's section. Accordingly we find this specimen to be a coarsely crystalline aggregate of silvery mica with quartz, the rock being stained pinkish in places from oxidation of iron in the mica. It is the most highly crystalline of all the rock-specimens. Those under the label *No. 4* are varieties of quartz, some



with pyrites. This exposure would seem to represent the granitic rise of the more southern parallel to which allusion has already been made.

Nos. 5 & 6. On either side of the next great bend of the Gascoyne river, and about 40 miles to the eastward of the last-noted exposure, are two hills, one on either side of the stream, known as Mt. Steere and Mt. James; the latter is marked in Mr. Gregory's section as about 2000 feet high, and as composed of metamorphic rock resting on "granite" pierced by dykes. It is represented by specimens No. 6 of Mr. Forrest's collection. One of these is a whitish quartzite or quartzose grit with a little mica and many specks and small crystals of magnetite. The second specimen is a very quartzose micaceous schist, or gneiss, similarly speckled with magnetite. These would seem to belong to Mr. Gregory's metamorphic rock indicated in his section by the symbol *i*. On the other hand the rock of Mt. Steere, No. 5 of the collection, is a schistose mixture of quartz and kaolin (?), and may be regarded as belonging to the more highly crystalline series. No. 8, from Mt. Packford, is simply concretionary carbonate of lime.

Sixty miles further east, and beyond the highest sources of the Gascoyne, is a hill marked Mt. Clere. No. 9, from this place, is a close-grained flaggy quartz-grit of a dun colour, which must be regarded as forming part of a sedimentary series but little altered in the direction of crystallization. Forty miles due north of this, at the head waters of the Lyons river, occurs a rock, No. 11 *a*, which may be described as a sort of yellowish grey phyllade. No. 10, from this district, is an opaque white chalcedony rust-coloured on the exterior, and No. 11 *b* is opal.

Quite in another direction, No. 12 is a kind of white flint. The beds from which this is derived may possibly be in the line of the prolongation of Mt. Kennedy Range.

*Palæontology*.—There are a few forms of doubtful nature to which no further allusion need be made. The Actinozoa are very fairly represented. Indeed, considering that only one doubtful *Cyathophyllum* was known previously from West Australia, the Forrest collection may be regarded as rather rich in this respect, and the specimens are free from matrix and nicely weathered, so that the characters can be made out fairly well. Of the rugose corals (*Zoantharia rugosa*) there are several specimens of what is, in all probability, a new species of *Amplexus*; one specimen of an *Amplexus* which is probably British, but new to Australia; and one specimen of a *Zaphrentis*, which may be new.

Amongst the group of corals, if, indeed, they are corals, which used to be called "tabulate," are several specimens of a branching form of *Stenopora*, which is probably identical with *Stenopora tasmaniensis*, Lonsdale.

All the above fossils are Carboniferous or closely allied to Carboniferous forms; but there is just one specimen of the Favositidæ, which has a Devonian look about it. Indeed this specimen might

almost be taken for the well-known *Favosites polymorpha*, which now figures as *Pachypora cervicornis* in correct lists of fossils. The above species has been quoted as occurring in the Lower Devonian of the Macleary river. This is the only trace of a thoroughly Devonian fossil in the whole collection. If really collected from the same beds as the others, its presence is somewhat singular. I can scarcely believe it to have been remanié from lower beds.

Portions of crinoidal stems are numerous in the collection; these probably belong to *Poteriocrinus* and *Cyathocrinus*. Along with these are many single "joints" and smaller fragments occurring together with pieces of Polyzoa, &c., in the matrix of the larger fossils, forcibly reminding one of the contents of Carboniferous rocks at home.

The Polyzoa also are well represented; and besides forms hitherto recognized as abundant in Australia, are others whose allies must be sought in America. There are two species of the very curious genus *Evactinopora*, only known hitherto, so far as I am aware, in the Lower Carboniferous of the Mississippi valley. Besides these are several specimens of *Fenestella plebeia*, common in the Carboniferous Limestone of Ireland, and quoted from nearly every Carboniferous locality in Australia. One of the many varieties of *Protoretipora* (*Fenestella*) *ampla* is also met with in the collection; of this there are two specimens.

The improvement in the list of Brachiopoda is not so great as in the lower forms of life just quoted; but Mr. Gregory's list is confirmed and strengthened. In Mr. Forrest's collection there occur one species of *Athyris*, four species of *Spirifer*, of which two belong to the alate group, and two species of *Productus*, one of which may be a *Strophalosia*. These are all from the "Range containing fossils," and there is a cast of an *Orthis*? from station No. 2, in all eight species of Brachiopoda.

Here, again, the whole facies is strongly Carboniferous, as will be seen on referring to the table of fossils, though one or two species, which have a great range both in time and space, are common to the Carboniferous and Devonian.

The Conchifera are represented solely by *Aviculopecten*, of which there are two species. The specimen of *A. illawarensis* is very fine. This fossil has a considerable amount of adherent matrix, consisting of a coarse red marly quartz-grit full of crinoidal fragments and of Polyzoa. Two fragmental casts of *A. limæformis* occur in a brown, ferruginous, fine-grained sandstone.

*Concluding remarks.*—If any doubt still exists as regards the age of the coal-bearing beds on the Irwin river, in lat. 29° S, and on the Fitzgerald river, in lat. 34° S, which were regarded by Mr. Etheridge as of Mesozoic age\*, it is at least satisfactory to know that a thoroughly Carboniferous fauna occurs in the "Range con-

\* See "Description of the Palæozoic and Mesozoic Fossils of Queensland. Quart. Journ. Geol. Soc. vol. xxviii. p. 320.

taining Fossils," which extends for so many miles towards the tropic, north of the Gascoyne river. No outcrops of coal appear to have been discovered; otherwise the Surveyor would surely have found room for a specimen in his collection. But where there is such an extensive range bearing Carboniferous fossils, coal-seams of that age may reasonably be expected somewhere along its flanks.

It may be worth noting that the Carboniferous beds of Queensland commence in lat.  $26^{\circ}$  S, and extend with some interruption almost to lat.  $20^{\circ}$  S, on the Bowen river. Thus the latitudes on the east side of the Australian continent, corresponding with the position of the "Range containing Fossils," are just those which possess the great development of Carboniferous beds described by the late Mr. Daintree\*, who tells us that "whilst the affinities of the southern coal-field of Queensland are Mesozoic, a northern field of even larger extent has a distinct fauna, more resembling the Palæozoic Carboniferous of Europe." He further states that in the lower strata *Producti*, *Spiriferæ*, &c., of true Carboniferous age, are associated with imperfect forms of plants resembling the *Glossopteris*, *Pecopteris*, &c., of the upper portion of the series. Numerous outcrops of coal had even then been noted in the group; but up to 1872 no commercial use had been made of them, owing to the difficulties of carriage.

Having drawn certain inferences from what there is in Mr. Forrest's collection, it may be permitted, though with more hesitation, to draw certain inferences from what there is not. It should be specially noted that no specimens of granite have been brought, so that the crystalline rocks are represented by schists such as numbers 3 and 5.

If the small rock-specimens are a fair sample of the country, it is evident that quartzose matter largely preponderates in the crystalline, subcrystalline, and plain sedimentary groups, whilst both opal and chalcedonic silica are not scarce. Notwithstanding the number of fossils limestone does not seem to be very characteristic of the district, and volcanic rocks are entirely absent.

With regard to the palæontological evidence, the only trace of a truly Devonian fossil is the *Pachypora*, which so much resembles *P. cervicornis* (*Favosites polymorpha*). On the other hand, although it is the fashion to speak of the Australian Carboniferous as Permo-Carboniferous, it may be well to remember that the representatives and nearest relatives of the species occurring in the Fossil Range, are found in the Lower rather than in the Upper Carboniferous of other countries. That the rocks of the Fossil Range are homotaxially Carboniferous there can be no doubt, whatever may be their place in time; and it does not seem necessary to suppose such a development of Permian beds, distinct from the Carboniferous, as is shown in Mr. Gregory's section.

\* *Loc. cit. supra.*

## APPENDIX.

Subjoined is a list of the fossils, with remarks on some of the species.

*List of determinable Fossils from the Forrest Collection\*.*

ACTINOZOA.		A	B	
<i>Zoantharia rugosa.</i>				
1.	<i>Amplexus pustulosus</i> , sp. n .....	3	2	
2.	— ? <i>nodulosus</i> , <i>Phillips</i> .....	1		
3.	<i>Zaphrentis</i> , sp. ....	1		
‘ <i>Tabulata</i> ’ ( <i>Favositidæ</i> ).				
4.	<i>Pachypora</i> ? sp. n .....	1		
†5.	<i>Stenopora tasmaniensis</i> , <i>Lonsdale</i> .....	2	2	
ECHINODERMATA.				
6.	<i>Poteriocrinus</i> , sp. } fragments of {	6	2	
7.	<i>Cyathocrinus</i> , sp. } stems only {			
POLYZOA.				
8.	<i>Evactinopora crucialis</i> , sp. n. ....	1		
9.	— <i>dendroidea</i> , sp. n. ....	3	1	
†10.	<i>Fenestella plebeia</i> , <i>McCoy</i> .....		3	{ in a very cal- careous rock.
†11.	<i>Protoretipora ampla</i> , <i>Lonsdale</i> .....	1	1	
MOLLUSCA.				
<i>Brachiopoda.</i>				
†12.	<i>Athyris Royssii</i> , <i>Leveillé</i> .....	3		
†13.	<i>Spirifer striatus</i> , <i>Martin</i> .....	2	1	
14.	—, cf. <i>crassus</i> , <i>Koninck</i> .....	1	1	
†15.	— <i>vespertilio</i> , <i>G. Sowerby</i> .....		1	
†16.	—, cf. <i>convolutus</i> , <i>Phillips</i> .....		1	
†17.	<i>Productus</i> , cf. <i>brachythærus</i> , <i>G. Sowerby</i>	1		
18.	— or <i>Strophalosia</i> , sp. ....	1		
19.	<i>Orthis</i> , species (cast) .....			{ 1 specimen mark- ed “2” in the coll.
<i>Lamellibranchiata</i> ( <i>Monomyaria</i> )				
†20.	<i>Aviculopecten illawarensis</i> , <i>Morris</i> .....		1	
†21.	— <i>limæformis</i> , <i>Morris</i> .....	1	1	
		28	17	1

N.B. In the accompanying remarks on the apparently new forms, it should be distinctly understood that I regard the specific names chosen as merely provisional. It became necessary to do something

\* Column “A” denotes the number of specimens of each species marked “1,” and believed to be derived from “Fossil Range” north of the Lyons river.

Column “B” denotes the number of specimens of each species *not marked*, but stated to come from “Fossil Range” near the junction of the Gascoyne and Lyons rivers, lat. 25° S.

† Species thus marked are quoted in Mr. Etheridge’s Catalogue of Australian fossils.



with these new fossils, and accordingly I have done the best I could under the circumstances. Palæozoic Corals and Polyzoa can only be *adequately* described by those who have made the subject their especial study.

1. *AMPLEXUS PUSTULOSUS*, sp. n. Plate XXIII. figs. 1a, 1b, 1c.

There are five specimens of a somewhat rugged *Amplexus* with broad septa, which cannot be referred to either of the two species of this genus hitherto recognized as Australian. Of these species *Amplexus arundinaceus* was first described by Lonsdale from a specimen in black limestone; but this is in such an imperfect state as to make a very bad *type*\* for comparison. However, the septa of *A. arundinaceus* are finer and more numerous, and it is pretty evident that there is no reason for De Koninck's suggestion† that it approaches *Zaphrentis cylindrica*, Scouler. Certainly the transverse section of the British-Museum specimen, bad as it is, would not lead one to suppose that the septa were continuous to the centre.

*Amplexus pustulosus* has more affinity with *A. Selwyni*, De Koninck‡, both in external form and in the size and number of the septa. In De Koninck's figure no epitheca is shown; but in the text the author speaks of it as being very fine; and no mention is made of any excrescences, such as form one of the distinguishing features of the species now under consideration. Moreover, the septa are probably rather more numerous in De Koninck's fossil.

Similar processes have been noted, though rarely, in other species of *Amplexus*. For instance De Koninck describes *A. lacrymosus*§ from the Carboniferous Limestone of the neighbourhood of Dinant, which has pustules like tear-drops. Curiously enough, he remarks that it has analogy with *A. arundinaceus*, "from which it differs principally by its spiniform appendages."

The corallum of *Amplexus pustulosus* is moderately large and slightly curved. The epitheca is of varying thickness in the different specimens, according to the state of preservation, and is furnished at rare intervals with processes which probably supported spines, but which in their present condition, greatly resemble pustules||. In a specimen about one inch in diameter, the number of septa is 42; they are slightly less in width than the intercostal spaces, and advance well towards the axis. All the three specimens figured have been more or less squeezed out of shape.

2. *AMPLEXUS*, cf. *NODULOSUS*. Phillips, Pal. Foss. of Cornwall, p. 8; De Koninck, Nouv. Rech. Terr. Carb. Belg. p. 74, pl. vi. fig. 5.

\* The type is in the British Museum, and no better specimen has been seen by me.

† Foss. Pal. Nouv. Galles du Sud, 1877, pt. 3, p. 149.

‡ *Op. cit.* p. 73, Atlas, t. 2. fig. 2.

§ Nouv. Rech. Terr. Carb. Belg. p. 76, pl. vi. fig. 7.

|| See figure 1a. Lest any one should be disposed to find a mare's-nest, it may be as well to draw attention to the resemblance which certain crinoidal fragments adhering to the epitheca and the matrix present to these pustules. Both are shown upon the figure.

## Genus STENOPORA, Lonsdale, 1844.

In a very able article which has recently appeared in the 'Annals of Natural History'\* , on Palæozoic Corals from Northern Queensland, Messrs Nicholson and Etheridge contend that Lonsdale's genus is a good one and worthy of being retained. They admit that, in transverse section, across a branch, for instance, the axial corallites are seen to differ in no essential feature of their structure from those of *Monticulipora* or *Favosites*. The tubes in this portion of the corallum are regularly polygonal, and are certainly, as a rule, in close contact. But in what they call tangential sections, taken a little below the surface, the characteristic feature of *Stenopora* is made manifest. Here it is possible to observe the periodical thickening which produces the annulations of the tubes in their outer portions†.

In Count Strzelecki's work‡ Mr. Lonsdale supplements his diagnosis, and describes four species which are figured in plate viii. Two of these are branching forms, viz., *Stenopora tasmaniensis*, and *Stenopora ovata*§. In the latter species those portions of the tubes tangential to the axis are very closely annulated, as is shown in the enlargement (fig. 3 a of pl. viii. in Strzelecki's work). The original specimen is in the British Museum, and testifies to the accurate drawing of Mr. J. de C. Sowerby. It is just weathered enough to display the internal structure, and in this way the close annulations of the "horizontal" portions are admirably displayed.

3. STENOPORA TASMANIENSIS, Lonsdale, 1844; Darwin's Geol. Obs. Volc. Islands, p. 161 (1844); Strzelecki's Phys. Desc. N.S. Wales, p. 268, t. 8. fig. 2 (1845).

There are four fragments in Mr. Forrest's collection belonging to a branching coral; the branches are subcylindrical, and were probably variously inclined or contorted; tubes more or less divergent; mouths slightly oval, indications of successive narrowing in each tube uncertain.

This agrees only moderately well with Lonsdale's description of *S. tasmaniensis* as given by Strzelecki, though on the whole these specimens have a considerable degree of resemblance to the figure in the plate. Since there is no specimen of *S. tasmaniensis* in the British Museum, actual comparison has not been practicable. I have failed to detect any accumulation or successive thickening either in the natural sections, or in those that have been cut, though a more practised eye might be able to do so.

It should be observed that Lonsdale himself merely says that

\* Ser. 5, vol. iv. pp. 265 *et seq.*

† Lonsdale's diagnosis of *Stenopora* concludes as follows:—"Corallites polygonal, thin-walled, and more or less completely in contact in the centre of the branches; but in the outer curved portion of their course, more or less cylindrical, and annulated by periodical ring-shaped thickenings" &c.

‡ Physical Description of New South Wales, pp. 262 *et seq.*

§ De Koninck made these species synonyms of *Chætetes tumidus*, and subsequently, having shown the existence of mural pores or perforations in *S. ovata*, he has referred it to the genus *Favosites*. Nich. and Eth. loc. cit.

"several casts of a racemose *Stenopora* were noticed in the collection [Count Strzelecki's] examined, but that they did not admit of complete identification." It is highly probable that Mr. Forrest's specimens belong to the species to which allusion is thus made.

Genus *EVACTINOPORA*, Meek and Worthen, 1865\*.

This genus was instituted for the reception of certain peculiar forms, which are, perhaps, more nearly polyzoan than actinozoan, but which are not very easy to understand. The following is the generic diagnosis:—

"Polyzoum free? consisting of a few large, more or less thickened and solid calcareous plates or laminae, radiating from an imaginary vertical axis, so as to present, in transverse section, a star-shaped or cruciform outline. Rays thickest and most dense on the under and outer edges; thinner and penetrated on either side by the pores within; each apparently divided along the middle by a thin lamina separating the inner ends of the pores of the opposite sides; substance showing in transverse sections a more or less laminated structure, the laminae being arranged parallel to the planes of the rays. Pores small, regularly arranged in quincunx, and separated by spaces equalling or exceeding their breadth."

Three species are described and figured from the Lower Carboniferous of Illinois and Iowa. The authors allude to the possibility of *Evactinopora* being the same as *Conodictyum* of Münster†.

4. *EVACTINOPORA CRUCIALIS*, sp. n. Plate XXIII. figs. 2 *a*, 2 *b*, 2 *c*.

Somewhat similar to Meek and Worthen's *Evactinopora grandis* (*op. cit.* p. 503, pl. 15. fig. 2, 2 *a*, 2 *b*), this one differs principally in the arrangement of the pores on the flanks of the rays. As may be seen in the enlargement of one of the rays (fig. 2 *c*), the pores or tubulated terminations leave quite a blank space or callus. This peculiarity completely disturbs the symmetry of the quincuncial arrangement, whilst the pores themselves, as a sort of compensation for being thrust out, are larger in immediate contiguity with these blank spaces.

The rays are four in number, as in *Evactinopora grandis*, and arranged in the form of a cross; the entire polyzoarium is very much smaller, but this may be merely a question of age. The laminated structure, mentioned in the diagnosis of the genus as being parallel to the rays, is remarkably well shown by the artist both in the cross section presented by the presumed base of the compound organism (fig. 2 *a*), and still better in the fracture-face of the fourth ray, enlarged (fig. 2 *c*). It is very evident that weathering develops and perhaps exaggerates this structure.

The specimen figured is the only one in the Forrest collection that can, with any certainty, be referred to this species.

\* Proc. Acad. Nat. Sci. Philad. 1865, p. 165. Meek & Worthen, Geol. Survey, Illinois, vol. iii. p. 501.

† Goldf. i. 103, pl. xxxvii. fig. 1; cf. also D'Archiac, Mém. Soc. Géol. France, vol. v. p. 369, pl. 25. fig. 1 (*Conipera cladiformis*).



5. *EVACTINOPORA DENDROIDEA*, sp. n. Plate XXIII. figs. 3 *a*, 3 *b*, 3 *c*, 3 *d*.

In this species the development is dendroid rather than cruciform, the rays or branches being cylindrical to ovate, and even flattened; whilst the arrangement is possibly triradiate, if we are to regard the specimen fig. 3 *a* as an original centre or nucleus. The other specimen figured (figs. 3 *b*, 3 *c*, 3 *d*) is believed to be a branch from a similar nucleus, and is in a very good state of preservation. All the external peculiarities with respect to the pores and the blank spaces are common to this and the previous species, and a very large series might possibly show connecting links. Still this form would seem to be triradiate rather than quadriradiate, the rays *usually*, though not always, having a tendency to be cylindrical.

A weathered fracture in the second specimen (fig. 3 *b*) gives a good axial section, which has been enlarged (fig. 3 *c*), but not enough, perhaps, to show the very complex tubular structure, though the lamination mentioned with reference to the previous species is very conspicuous. Indeed the lamination is so brusque that it very much interferes with a correct understanding of the relations between the very fine axial tubes and the larger lateral ones. A study of this specimen seems to indicate that the laminated portion of the general structure is confined to the region of the large lateral tubes, as the central portion is free from lamination and in a somewhat different mineral condition. Owing to unequal development, this ray is very unsymmetrical in this portion of its course, and thus where there is a fresh manifestation of the fine vertical tubing, the absence of lamination again coincides. Whether this has any structural significance it is impossible to say.

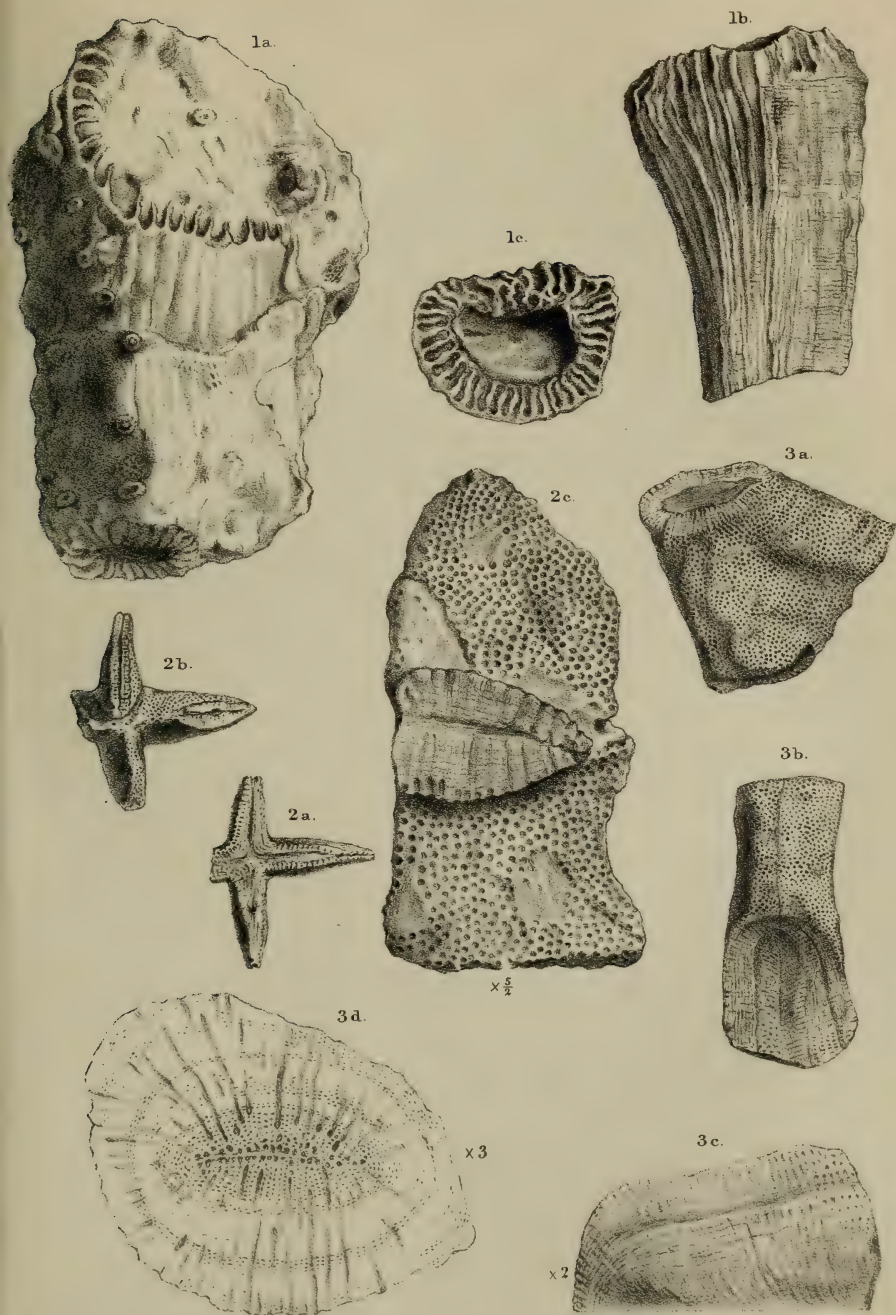
The transverse section (fig. 3 *d*) of this same branch, or ray, shows us the tubular systems from a different point of view; whilst the laminar structure is much less apparent. Here we obtain a good view of the division along the middle by the "thin lamina separating the inner ends of the pores of the opposite sides," the central axis, as it were, of the ray or branch. The relation of the axial or vertical tubes to the lateral ones is never to be made out in these transverse sections; but we learn that the larger tubes are sparingly tabulate\*, and we also perceive unequally developed zones of the small tubes at intervals in the more external portions, which are, I suppose, connected in some way with the growth of the stock.

There are two other specimens in the collection which may belong here†.

\* Dr. G. J. Hinde has drawn my attention to the circumstance that in Nicholson's work on the Monticuliporidæ forms are depicted which, as regards their internal structure, are not unlike *Evactinopora*. At page 88, *Heterodictya*, an undoubted polyzoan, is shown to have well-developed tabulæ.

† In the Mém. Soc. Géol. France, 2 sér. t. 2, pt. 1, there is a paper by M. D'Archiac on fossils from the Nummuline beds of the neighbourhood of Bayonne, in which he describes, under the name of *Guettardia Thiolati* (p. 197, pl. v. fig. 15, and pl. viii. figs. 5, 6, 7), an organism somewhat resembling this. He refers it to Michelin's genus *Guettardia*, which is generally regarded as a sponge.





A.S. Foord lith.

Mintern Bros. imp.



## 6. FENESTELLA PLEBEIA, M'Coy, 1844.

*Fenestella plebeia*, M'Coy, Synop. Carb. Foss. Ireland, p. 203, t. 29. fig. 3 (1844).

*Fenestella fossula*, Lonsdale, Darwin's Geol. Obs. Volc. Isl. p. 166 (1844).

*Fenestella fossula*, Lonsd. in Strzelecki, p. 269, t. 9. fig. 1 (1845).

Besides three well-preserved fragments of this world-wide species, there are numerous indications of it in connexion with other fossils.

## Genus PROTRETIPORA, De Koninck \*, 1877.

## 7. PROTRETIPORA (FENESTELLA) AMPLA, Lonsdale, 1844.

*Fenestella ampla*, Lonsdale in Darwin's Volc. Isl. p. 163 (1844).

*Fenestella ampla*, Lonsd. in Strzelecki, p. 268, t. 9. figs. 3a-d (1845).

There are two specimens in the Forrest collection.

Mr. Etheridge, junior, remarks that the group is subject to great variation, being very abundant in what he calls the Permo-Carboniferous of Australia, and fining down through infinite gradations to a smaller mesh.

## EXPLANATION OF PLATE XXIII.

Fig. 1a. Compressed specimen of *Amplexus pustulosus*, n. sp., showing the tubercles on the epitheca. Nat. size.

1 b. A smaller specimen, also compressed, having the epitheca partly removed. Nat. size.

1 c. Transverse section of a third fragment, also pressed out of shape.

2 a. Under side of *Evactinopora crucialis*, sp. n. Nat. size.

2 b. Upper side of same specimen. Nat. size.

2 c. Do., flank view, magnified  $2\frac{1}{2}$  times.

3 a. Triradiate nucleus of *Evactinopora dendroidea*, sp. n. Nat. size.

3 b. Branch of another specimen of *E. dendroidea*. Nat. size.

3 c. Portion of ditto, showing an axial section,  $\times 2$  diam.

3 d. Transverse section of ditto (slice on glass),  $\times 3$  diam.

## DISCUSSION.

Prof. BOYD DAWKINS pointed out the similarity of the sequence in Western Australia with that long ago established as occurring in Eastern Australia.

Mr. J. C. CRAWFORD pointed out the fact that, though Carboniferous rocks occur in West Australia, there is no coal yet known there; and referred to the difficulty of deciding as to the age of the coal of Australia.

The AUTHOR, in reply, stated that the coals of Australia appeared to be of two different ages, Palæozoic and Mesozoic. There is no proof of the presence of Devonian strata in Western Australia.

\* Foss. Pal. Nouv.-Galles du Sud. pt. 3, p. 178.

34. *On the RELATIVE AGES of CERTAIN RIVER-VALLEYS in LINCOLNSHIRE.* By A. J. JUKES-BROWNE, Esq., B.A., F.G.S. Communicated by permission of the Director-General of the Geological Survey. (Read June 20, 1883.)

#### INTRODUCTION.

IN a country which is traversed by a series of escarpments or hill-ranges, the valleys by which its drainage is effected are usually separable into two sets or systems, one parallel to the strike of the ridges, and the other more or less at right angles to the same. The origin of these longitudinal and transverse valleys, and the process by which escarpments have been intersected by river-valleys, were first explained by Mr. Jukes\*. He showed also that in the case of a river cutting through a ridge or escarpment, and receiving tributaries from the longitudinal valleys which are parallel to this ridge, the primary or first-formed stream is that opposite to the breach in the escarpment, and that the longitudinal branches, though often of much greater length than this primary stream, are really of secondary or subsequent origin.

Stated in general terms, his theory amounts to this, that the original direction of all rivers which cut through ridges was determined by the general slope of the ancient surface over which they began to run, and that when the slope was transverse to the strike of the beds, the channels cut by the earliest rivers necessarily had a similar transverse direction, while the channels in the longitudinal valleys were formed subsequently and concurrently with the development of the ridges or escarpments.

A further corollary to this may, I think, be considered as generally true, viz., that those portions of a river-valley which intersect the same ridge date from the same epoch of time; and that rivers flowing between the same two parallel ridges came into existence at the same time.

It does not follow, however, that the channels of all the primary transverse streams were permanently maintained; the extension of a longitudinal tributary may intercept the drainage of minor transverse streams. Thus in fig. 1, A, B, C, are three transverse streams, each of which originally ran across the ridge DR as indicated by the dotted continuations of B and C; but the extension of the tributary T has intercepted the waters of B and C.

Jukes, writing of the river-valleys in the south of Ireland, expresses this as follows†:—"The longitudinal valley may even be worn back across the course of many minor transverse streams, and deflect their waters down its course." He also observes that "to

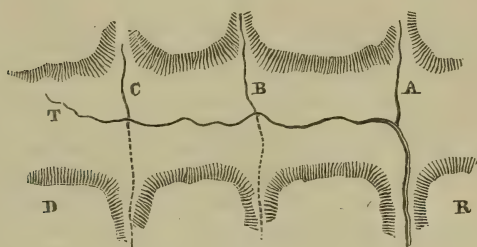
\* Quart. Journ. Geol. Soc. vol. xviii. p. 378 (1862).

† Manual of Geology, 3rd ed. p. 456 (1872).



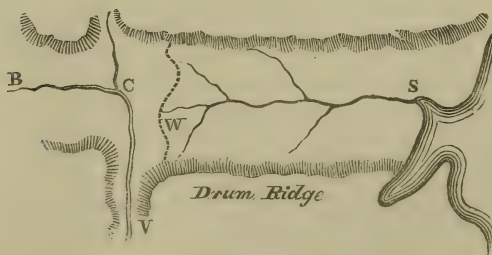
whatever extent these longitudinal valleys might proceed, none of the waters coming down them could ever cross the lowest original transverse valley that was formed by the little primary river;" and he points out that the river Blackwater has never crossed the primary transverse channel which runs southward from Cappoquin in Waterford, and never could do so unless something happened to cut a channel lower down the remainder of the longitudinal valley to Dungarvan Bay, and deeper than the channel already cut down to Youghal Bay.

Fig. 1.—*Diagram of a Stream intercepting earlier Transverse Streams.*



To suppose the possibility of such a channel being formed, in any case was entirely outside the scope of Jukes's argument; but the sequel will show that it is worth while considering this possibility, and calculating the results which would follow from the development of such a channel.

Fig. 2.—*Diagram of probable changes in the Valley of the Blackwater.*



Suppose, therefore, that a small stream ran into Dungarvan Bay as at S in fig. 2, and that while the valley of the Blackwater was extending itself westward from Cappoquin, the valley of the stream S was also extending itself westward from the coast. It is clear that

the base-level to which the stream would cut down at its mouth, S, would be much lower than the bottom of the Blackwater valley at C; and just as the Blackwater may have intercepted and diverted certain transverse streams to the westward, so might the stream S have intercepted the waters of the main river at C. In this process the detritive action of rain in lowering the retreating watershed (W) would be as much concerned as the action of the stream in eroding its channel and transporting detritus; and the whole process would form part of the gradual development of the longitudinal valley in the manner explained by Jukes. Eventually the watershed W might be so lowered that the difference of level between the Blackwater at C and the upper tributaries of the stream S might be very slight; and during a time of flood the waters of the main river might force a way into the channels of these tributaries. When once this diversion was effected, the river would not be likely to regain its former course through the narrow gorge at V, which would be ultimately converted into a dry pass or gap through the ridge; and the channel of the Blackwater would be confined to the longitudinal valley north of the Drum ridge, and would appear as a river running from west to east and emptying itself into the sea at Dungarvan Bay.

The final result, therefore, of the whole process might have been this, that the course of all the transverse streams which originally crossed the Drum ridge from north to south, might have been diverted into the longitudinal valley, and so have been converted into one continuous river flowing from beginning to end in this longitudinal valley from west to east. At the same time the volume of water in the original valley of the Blackwater south of the Drum ridge would be very greatly diminished, owing to the great contraction of its drainage-area by the diversion of its upper tributaries. I have no doubt that a very good reason can be found why this last diversion did not happen in the case of the Blackwater; but what local conditions prevented from happening in that case may have happened in other cases, and I have only used the instance of the Blackwater in order to make my meaning clear.

I will now, therefore, state in general terms the special thesis which I hope to establish in the following pages. Wherever a succession of escarpments and intervening longitudinal valleys has been developed out of a surface of marine denudation, and a river crosses any one of the longitudinal valleys which happens to stretch to the sea-coast, then this transverse river is liable to interception and diversion by the backward extension of a stream flowing down the longitudinal valley into the sea or into a tidal estuary.

In considering the possibility of such an occurrence it must be remembered that most escarpments have an inclination in the direction of their strike, and that their base-line often has a decided slope from a given point inland towards their termination at the sea; in such cases the intervening valleys have a general slope in the same direction. It is only under such conditions that the intercepting stream could come into existence, and that it could extend itself up the longitudinal valley far enough to intercept the inland

and previously established course of a transverse stream. I now proceed to describe two cases in which I believe such an interception has taken place.

#### THE CALCEBY AND STEEPING BECKS IN LINCOLNSHIRE.

*Relative Position of their Valleys.*—The tract of country which is drained by these two streams lies at the southern extremity of the Lincolnshire Wolds, which here consist of two nearly parallel ranges of hills, the eastern range being that of the Chalk Wold, the western consisting of Neocomian sandstones and clays capped by Boulder-clay. Between these two ranges lies the broad valley of the Steeping, which has been cut down through the Neocomian strata into the underlying Kimmeridge Clay; while the chalk range is completely severed into two portions or masses by a deep and narrow valley which gives passage to the Calceby Beck. The latter is therefore a transverse valley, and the former a longitudinal one; but their relation to one another is not that which ordinarily exists between transverse and longitudinal valleys. The stream in the longitudinal valley is not a tributary of the other, but flows away from it, and the upper part of its valley lies at a lower level than the adjoining part of the transverse valley.

The transverse valley is thus abruptly truncated and cut off from receiving the brooks rising on the high ground to the westward, which would naturally drain into it, but for the interposition of the longitudinal valley of the Steeping. It is difficult, therefore, to understand how the transverse valley could have originated, if the former configuration of the district was at all similar to that which it now presents.

Both streams now rise in the neighbourhood of Tetford, a village about eight miles south of Louth. The Calceby Beck has its sources among the hills east of that village, the numerous springs which issue from the base of the Chalk forming several small brooks which unite below the small hamlet of Calceby, and thence flow north-eastward to South Thoresby. Near Calceby it also receives the water of a tributary from the N.W. flowing in a longitudinal valley, which has a much greater length than any of those which unite at the head of the main valley.

Another tributary comes in near South Thoresby, and springs swell its volume near Belleau, where the stream emerges into the broad undulating plain of Boulder-clay which intervenes between the chalk hills and the marshes along the coast. Through this plain the river pursues its north-easterly course in a shallow valley past Claythorpe and Withern, where it passes into the marshland, and is carried northward between raised banks to the sea-coast at Saltfleet.

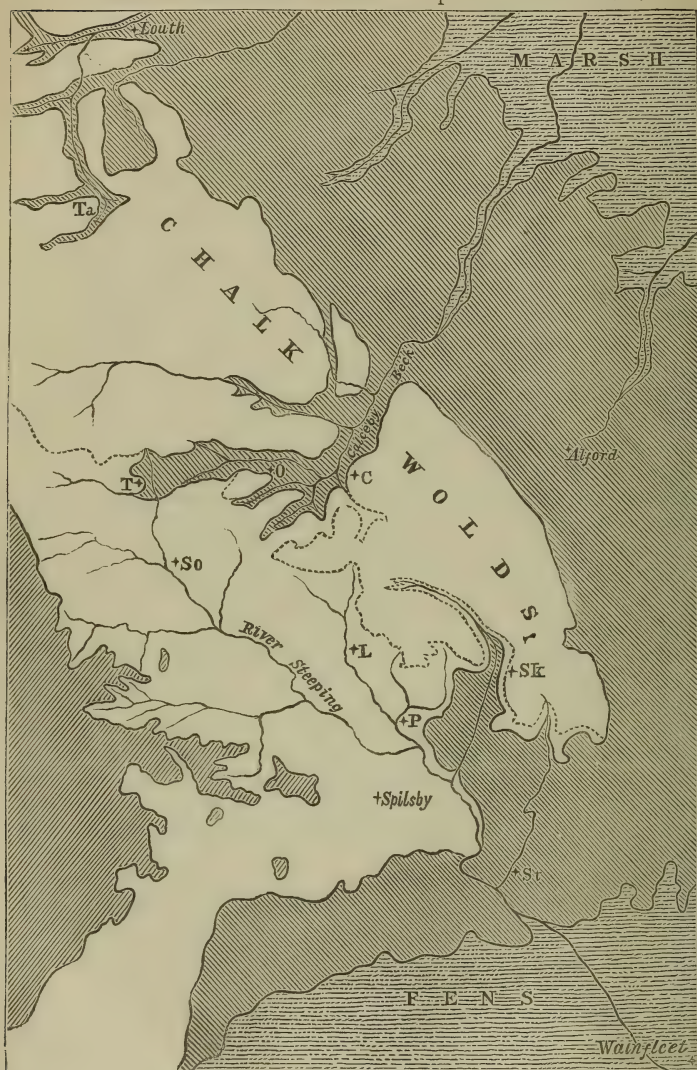
If we now turn to trace the course of the Steeping river, we find that its head waters are formed by a brook which rises near Belchford, and flows westerly through Tetford. The valley of this brook is continuous with the Ormsby valley, through which flows a tributary of the Calceby Beck; but the Tetford brook instead of



Fig. 3.—Map of part of Lincolnshire.

(Scale  $3\frac{1}{2}$  miles to 1 inch.)

The dotted line indicates the escarpment of the Chalk.



Chalky Boulder-clay.

Purple and Hesse Boulder-clays.

St = Great Steeping.  
 P = Partney.  
 Sk = Skendleby.  
 L = Langton.

C = Calceby.  
 So = Somersby.  
 T = Tetford.  
 Ta = Tathwell.



pursuing what appears to be its natural course, turns southward at right angles, and passing through a narrow gorge, issues into the broad valley of the Steeping at Somersby. Three other tributaries descend from the high ridge above described on the western side of this valley; and another from the eastern side, which, like the Tetford brook, looks as if it had once flowed N.E. into the Calceby valley, but now turns southward through Harrington Carr into that of the Steeping.

The united waters of these brooks flow south-eastwards by Saus-thorpe, Partney, and Ashby, receiving two more tributaries from the north, viz. the Langton and Skendleby Becks. At Ashby near Spilsby the stream turns southward, and passing between the villages of Great and Little Steeping, it enters the broad plain of the Fenland, and is conducted by a series of dykes to the outfall near Wainfleet. It is worthy of remark here that the entrance to the Steeping valley between Spilsby and Partney is very narrow compared with its breadth higher up and nearer its source.

The peculiar relations of the Calceby and Steeping valleys at once suggest that the first has been excavated by streams flowing eastward from the Neocomian hills, before the upper part of the Steeping valley had its present extension; and that these streams, which were originally the head waters of the Calceby Beck, were, by the subsequent formation of the Steeping valley, intercepted and diverted into that valley.

*Disposition of the Glacial Deposits.*—This view of the relative ages of the two valleys receives strong confirmation from the disposition of the glacial beds, and the extent to which they enter the two valleys.

The eastern flank of the Chalk Wolds is bordered by a great mass of Boulder-clay, including beds of sand and gravel, and belonging to the series known as the Purple and Hesse Clays. These deposits are in many places from 60 to 80 feet thick, and are banked up against the chalk hills, sometimes sweeping over and resting on their tops. These clays and gravels enter many of the valleys which open eastward, but are totally absent from others which drain in the same direction, the natural inference being that the Boulder-clays are posterior to the excavation of some of the valleys and anterior to the erosion of the others.

Now the valley of the Calceby Beck is largely occupied by these glacial accumulations; at its mouth between Belleau and South Thoresby the ancient bed of the valley is probably 50 or 60 feet below the present surface; and the glacial beds can be traced continuously to the very head waters of the present stream, and far up the valleys of the two tributaries which come in from the N. W. A great mass of clay and gravel blocks up the space where the ancient outlets of these two tributaries into the main valley appear to have been, so that the streams have been obliged to excavate deep and narrow channels through the solid Chalk on either side of this massive obstruction. Up the Ormsby valley Boulder-clay can be traced along one side of the park, and then gives place to a wide

spread of gravel, sand and loam, which forms an open plain between Ormsby Park and Tetford, the glacial age of the whole being proved by an intercalated patch of Boulder-clay near the western end of the deposit and beyond the present sources of the Calceby Beck.

It appears therefore that the Calceby and Ormsby valleys are choked up with glacial deposits, and that the present beck has not been able to excavate its channel down to the bed of the ancient river by which the valley was originally formed.

If we now turn to the Steeping valley we find that the Boulder-clays sweep round the southern end of the Chalk Wolds into the bay-like entrance of this valley, and extend in a narrow tongue far up the tributary valley of the Skendleby Beck, which comes in from the northward. Beyond the village of Partney, however, about a mile above the point where the Skendleby Beck enters the main valley, not a trace of glacial clay or gravel is to be found; the Boulder-clay terminates abruptly at this point, and not the smallest remnant exists further up the main valley or in any of its other tributaries to indicate that it ever had any further extension. This limit is only about two miles distant from a line drawn across the mouth of the valley from Halton to Candlesby.

The ancient outlet of the Skendleby Beck is buried beneath the glacial deposits\*, and is doubtless at a much lower level than the present bed of the Steeping river. This stream has excavated a channel through the western edge of the Boulder-clay, and down to the underlying Kimmeridge Clay, being evidently turned aside by the great mass of the Boulder-clay which fills up the bay-like entrance to the valley.

It is worthy of remark in this connexion that the gravels here intercalated between the upper and lower sheets of Boulder-clay have yielded an abundance of mammalian remains.

From the termination of the Boulder-clay near Partney to the furthest point at which the Kimmeridge Clay is exposed, viz. near Salmonby, is a distance of seven miles; it would appear therefore that the Lower Neocomian sandstone has been stripped off the Kimmeridge Clay throughout the whole of this distance during the time which has elapsed since the formation of these Boulder-clays; that is to say, the greater part of the Steeping valley is entirely of Postglacial origin. On the other hand the whole of the Calceby valley was formed before the accumulation of the Purple and Hesse Clays†.

*Mode in which the Steeping Valley was formed.*—I have already mentioned that the valley of the Tetford Beck is really continuous with that of the Ormsby Beck, the intermediate portion being a

\* See Quart. Journ. Geol. Soc. vol. xxxv. p. 403.

† Mr. S. V. Wood makes a great distinction between these clays, and even excludes the so-called Hesse Clay from the Glacial series altogether. I have not been able to detect any sign of unconformity between them, but on the contrary believe that they are parts of one continuous series, though I am still in doubt as to the exact relations of this red and purple series to the Chalky Boulder-clay.

broad plain between two of the steep hill-ridges into which the chalk escarpment is here cut up. This plain now forms the watershed between the Calceby and Steeping valleys; its centre is occupied by a broad strip of peat and alluvium, the western end of which drains into the Tetford Beck and the eastern end into the Ormsby Beck. This plain only exists because the ancient valley is choked up with glacial sand and gravel; and it is perfectly clear that if these accumulations were removed, the Tetford brook would continue its easterly course into the Ormsby brook, and so into the Calceby valley. Indeed, the strip of alluvium indicates that this was the course of the brook up to a very recent period (geologically speaking), and that it was only deserted when an easier exit was found by the present channel.

The cause of this diversion now remains to be considered, but is not far to seek. The broad ridge of Neocomian sandstone which lies to the south of Tetford is traversed by a deep and narrow trench, and through this the brook now escapes from the upper plain, and descends to the lower level of the Steeping valley. It could not have done this until the spring-heads of the Steeping had receded to their present position.

It is most probable that this trench was originally formed by a small tributary of the Tetford brook, draining the district to the southward and running northward to join it below Tetford. The drainage-basin of this tributary was gradually invaded and sapped by the recession of the spring-heads on its southern border, until it ceased to convey any water into the Tetford valley and its northern portion would remain as a dry trench. As the combined action of rain and springs carried the head of the Steeping valley further and further back, they worked down to a lower base-line than that of the Tetford valley, and the Kimmeridge Clay was gradually bared along the course of this dry trench. The strong springs which now issue from the base of the sandstone in this trench near Somersby, show how the work was done. Eventually when the country had assumed its present configuration, and probably when the Tetford brook happened to be in flood, the waters overflowed from the Tetford valley along this trench into that of the Steeping; and when this communication was once established it would be maintained, because, being cut down to a lower base-line, the fall along the new channel is much greater than that along the old one.

If this was the manner in which the Tetford brook became part of the Steeping-river system, it is very likely that other streams may originally have drained into the Calceby valley, and have been diverted in the same manner.

The breadth of the valley in which Brinkhill stands, its occupation by sand and gravel which is continuous with the drift of the Calceby valley, and its abrupt termination, are all facts suggestive of its once having had a longer extension to the south-west. In all probability the beck which rises near Warden Hill, and now flows southward through Harrington Carr, was originally a tributary of a stream flowing N. E. down the Brinkhill valley into the Calceby



Beck. Its diversion into the Steeping valley may have been effected in exactly the same way as that of the Tetford brook.

Before the diversion of the Tetford brook the extreme sources of the Steeping river would be at Salmonby; and before the diversion of the last-mentioned brook, the sources of the Steeping were probably near Stainsby; and at some still earlier period, all the streams draining the country north of the ridge on which Hagworthingham stands, ran north-eastward into the Calceby valley.

The mapping of the district by myself and Mr. Strahan, leads us to conclude that before the oldest Boulder-clay was laid down, the chalk escarpment occupied a more westerly position, and the line of the Steeping valley was occupied by the broad outcrop of the Middle Neocomian clay, with valleys opening south-westwards and drained by brooks running in that direction. On this surface the so-called *Chalky* Boulder-clay was deposited, and was probably banked up to the then edge of the Wold escarpment, as is the case further north. When detritive agencies began to operate on this district the rain which ran southwards would find a line of weakness along the junction of the Boulder-clay with the Wold scarp. A valley opening southward, or south-eastward, would in process of time be excavated along this line, just as the upper valley of the Bain has been formed under similar conditions. Its bottom for a considerable distance would be formed by the Middle Neocomian clay, and it would be some time before the Lower Neocomian sandstone would be bared to any great extent above the position of Partney. It is not unlikely that the beck coming down from Langton and Sutterby, and joining the Steeping at Partney, may indicate the course of this line of drainage. The Skendleby Beck was clearly also in existence at this time, and the united streams would doubtless flow south-east to the coast-line wherever that was.

As, however, the work of pluvial detrition went on, and a larger and larger area of the Lower Sandstone became exposed, a great proportion of the rainfall would be absorbed by the sandstone, and thrown out from its base in the form of springs. This would necessarily introduce a new element among the agencies of erosion, and the combined action of rain and springs would cause the valley to be extended in a north-westerly direction along the strike of the sandstone, far more rapidly than in any other direction.

Under these circumstances there is nothing improbable in the hypothesis that the whole of the present valley from Partney to Salmonby has been excavated in Postglacial times, and that, being cut back along a lower base-line, the Steeping river has gradually intercepted the drainage of a district which was once a part of the Calceby-beck system.

This therefore appears to be a case in which the extension of a longitudinal valley has intercepted and diverted the course of certain streams which originally flowed into a transverse valley, and has entirely altered the drainage-system of a considerable district.

The conclusions to which I have been led by a prolonged study of this part of Lincolnshire are opposed to those of Mr. S. V. Wood



on almost every point which he has raised in his recent memoir\*. Relinquishing his older opinions regarding the formation of Boulder-clays, he has adopted the theory of their terrestrial origin, and finds evidence of a theoretical ice-cap where other eyes can only see the results of ordinary rain- and river-erosion. He even goes so far as to doubt the capacity of certain rivers to make their own valleys, and does not believe that the rivers of Lincolnshire or East Anglia "had anything to do with the excavation" of the valleys in which they flow. He prefers to attribute the excavation of these valleys to the rush of waters produced by the melting of a mass of ice on the top of the chalk escarpment in Lincoln and Norfolk.

To any one familiar with the work of rain and rivers such an idea must seem highly improbable, and to any one who can visit the valley of the Steeping, and will note the wonderful series of dales, combes, and hollows which have been fretted out of the edge of the Lower Neocomian sandstone, and which are so evidently due to the action of rain and springs, Mr. Wood's hypothesis must seem extremely unlikely and utterly unnecessary. A mere inspection of the Geological Survey map, in fact, will afford sufficient grounds for deciding between the two explanations.

Mr. S. V. Wood confuses the two distinct valleys of the Bain and Steeping with the general trough-line in which they lie, and which he calls the Bain-Steeping trough. Now there is nothing remarkable about this trough; it is merely the re-excavation of the Preglacial scarp-foot, and has been widened into a trough by the recession of the chalk escarpment on the one side and the edge of the Boulder-clay on the other side, this widening being due to the agency of rain and springs, and having been in progress ever since the formation of the Boulder-clay. In that portion of the trough which lies between the valleys of the Bain and Steeping there is a floor of Middle Neocomian clay stretching continuously from side to side; but the Steeping valley is a hollow within the trough, and is cut down through the Lower Neocomian sandstone, and into the Kimmeridge Clay.

Mr. Searles Wood has noticed the limitation of the so-called Hessle Clay to the entrance of the Steeping valley, but does not offer any explanation of this peculiar portion, merely remarking that if the clay were an aqueous accumulation it should stretch up the valley to the levels which it reaches elsewhere†. I am still of opinion that the Hessle Clay is a marine accumulation, and offer the simple explanation that at the time when the clay was formed, the upper part of the valley in question had no existence. According to my view the formation of the Hessle Clay took place at an early epoch in the history of the valley, and when its excavation had not proceeded farther than the first stage described on p. 604, its entrance as far as Partney being an open bay, into which the Langton and Skendleby Becks emptied themselves.

If Mr. Wood's views regarding the age and origin of the Steeping

\* Quart. Journ. Geol. Soc. vol. xxxiv. p. 457, and vol. xxxviii. p. 667 (1882).

† Quart. Journ. Geol. Soc. vol. xxxviii. p. 715.

valley be admitted, the absence of the Hessle beds is apparently an inexplicable fact; for, whether these beds have been accumulated under aqueous or terrestrial conditions, it is equally surprising that no trace of them should occur in this valley (if it was then in existence) when they extend so far up the adjoining Calceby valley.

What therefore is such a puzzle on Mr. S. V. Wood's hypothesis, is but a necessary consequence of my postulate that the longitudinal valley is of later date than the transverse valley. I may therefore reasonably regard the position of the Hessle Clay in the Steeping valley as a confirmation of my belief that the whole of that valley above Partney has been excavated in Postglacial times, *i. e.* since the formation of the Hessle Clay, which I regard as the uppermost member of the Glacial series.

#### TRENT AND WITHAM VALLEYS.

*Modern Course of the Trent.*—This river is formed by the union of several streams, of which the most important are the Trent, the Dove, and the Derwent, flowing from the north-west off the Derbyshire and North Staffordshire watershed, the Tame and the Soar flowing from the south through the counties of Warwick and Leicester. These streams converge towards a point about ten miles S.S.E. of Derby, their united waters being known as the river Trent, which flows onward in a north-easterly direction through a well-marked valley as far as Newark.

Here, however, the river bends to the northward, keeping to the west side of the low Rhætic escarpment, as if it had not been able to cross that comparatively slight obstruction. This northerly course it maintains till it reaches the estuary of the Humber.

Now the course of the Trent as far as Newark favours the supposition\* that it was determined by the westerly slope of a plane of marine denudation across the edges of the Lower Jurassic strata; but if so, and if it had ever flowed over a surface of Oolitic rocks, why did it not continue this course so as to run in a transverse valley through the Oolitic escarpment and into the Wash instead of into the Humber?

It is a significant fact that if the general course of the Trent, south-west of Newark, be prolonged to the N.E., it points to the great gap in the Oolitic escarpment at Lincoln, through which the river Witham now flows. If this transverse gap or gorge be considered only in relation to the small river which runs through it, the manner of its origin is altogether inexplicable; but if good grounds can be shown for supposing that the river Trent formerly passed through it, the existence of such a gap is satisfactorily accounted for.

Moreover the anomaly in the present course of the Trent is likewise explained, if it can be shown that the northerly bend of that river is a subsequent diversion and not its original course.

\* Ramsay, *Phys. Geogr. and Geol. of Gt. Britain*, ed. v. p. 518.

*Ancient Gravels of the Trent.*—The width of the valley within which the Trent flows from Nottingham to Newark is remarkably even and uniform, the gravels and alluvium taken together forming a long straight tract with a breadth of from  $1\frac{1}{2}$  to 2 miles. Throughout this portion of its valley the river has a tendency to impinge upon its right bank, so that the higher and older gravels occur chiefly along the north-western side of the valley, and appear to lie entirely within the bounding slope of the valley on that side. By the Lowdham and Thurgarton stations on the Nottingham and Lincoln railway these gravels form a continuous terrace, which slopes gently down to the modern alluvium of the Trent.

Near Newark, however, the relations between the older gravels and the modern valleys begin to change; they are found on the eastern bank and stretch away from the river south of Newark and Beacon Hill, forming a continuous tract of gravel-covered country, which extends in a north-easterly direction between the modern valleys of the Trent and Witham. From Coddington, near Newark, the tract passes by Stapleford and Thurlby Moors to Swinderby, and thence it is continued on either side of the Midland Railway as far as Boultham near Lincoln, and only a mile from the entrance to the transverse valley through the Oolitic escarpment.

To Mr. Penning, who began to map these gravels from the Lincoln end in 1878, belongs the credit of suggesting that they represent the ancient course of the Trent; and he would doubtless have brought the subject before the notice of the Society, had not ill health obliged him to leave England and afterwards to resign his post on the Geological Survey.

It is also interesting to note that the Trent was joined by a powerful tributary from the south just before it reached the Oolitic escarpment. The proof of this statement is to be found in a clearly defined tract of gravel which stretches for many miles over the Lias plain below the Oolitic escarpment. This stream appears to have had its source among the hills near Belvoir Castle, where the small river Devon now rises; we may therefore consider this as the course of the ancient Devon, which then ran northward to join the Trent, just as the modern Brant joins the Witham near Aubourn. The Brant, indeed, may be regarded as the attenuated representative of this ancient Devon.

This line of gravel is traversed by the modern channel of the Witham between Hougham and Westborough, about six miles N.W. of Grantham, but continues northward along the ground between the present valleys of the Witham and the Brant as far as Aubourn, where it is again cut through by the Witham. Small patches, however, still remain near South Hykeham, on the northern side of the Witham valley, and lead on to the wide spread of sand and gravel by North Hykeham and Boultham, already mentioned as part of the Trent gravels.

This long tract of river-gravel is in every respect comparable to those which I have elsewhere described as existing in Cambridgeshire, and which so clearly connect themselves with the ancient



lines of drainage proceeding from the chalk escarpment. Mr. S. V. Wood has recently accounted for these in a very different way, and imputes to me the extraordinary postulate that I suppose a river to be capable of converting the centre of its bed into a hill\*. My sections are simply illustrative of the fact that the general surface of the country has been so lowered by the action of rain and rivers since the time when the drainage was diverted from these old channels, that the gravels of the older rivers now form ridges with slopes on both sides; but if one of these ridges is traced towards the hill country, it gradually comes to occupy the position of a terrace lying on one slope of a valley side.

In the case of these old Devon gravels, the Witham on the one side and the Brant on the other have cut down to lower levels, and left the gravels of the ancient Devon on the top of the intervening ridge.

Strong confirmatory evidence, almost amounting to proof, of the hypothesis that the Trent once flowed through the Lincoln gap, is furnished by the composition of the gravels which occur on the western side of the strip of Fenland that forms the modern continuation of the valley. These gravels will be described in the Geological Survey Memoir on Sheet 83; but the point of interest in connexion with my present subject is that they are largely made up of rounded pebbles of quartzite, hornstone, and other old rocks, which have evidently been derived from the Triassic pebble-beds of the west.

The presence of these pebbles in such large quantities on the eastern side of the Oolitic escarpment, and in gravels which border the Witham valley, seems inexplicable except on the hypothesis of their having been brought by the Trent through the gap at Lincoln.

There is, therefore, every reason to believe that in early Post-glacial times the Trent flowed along the course above indicated from Newark to Lincoln, and from Lincoln south-eastward to the Fenland, which was then probably an open bay. It remains then to indicate the causes which seem to have operated in diverting the river from the ancient course to its present channel.

*Diversion of the Trent.*—The Humber flows in a transverse valley, which has been cut down to a lower base-line than the Witham valley at Lincoln; and the rivers which flow into it have always been able to keep the passage open. Consequently the longitudinal valley formed along the tract of soft Keuper marls has continually extended itself southward, and the river in this valley must also have shifted its channel continually eastward, as the escarpment of the Rhætics receded, and the Humber valley was cut down to lower and lower levels.

The river running northward along this valley would be supplied by the brooks flowing from the west and draining the tract of Bunter sandstones, and has ultimately developed into the river Idle, which now rises near Mansfield, and pursues a north-easterly course parallel to that of the Trent.

I assume, therefore, that when the Trent ran *viâ* the Lincoln

\* Quart. Journ. Geol. Soc. vol. xxxviii. p. 673.



valley to the Wash, the Idle ran *via* the present Trent valley north of Gainsborough to the Humber. The watershed between the Trent and the Idle was then continuous, but was of course very low where it crossed the Keuper marls by Tuxford, Marnham, South Clifton, and Harby.

The rills draining the northern slopes of this low watershed would naturally be collected into a stream running northwards along the valley subsequently usurped by the Trent, and falling into the Idle somewhere north of Gainsborough. In these early Postglacial times, the elevation of the land above the sea was probably higher by 40 or 50 feet than it is now; the rivers consequently had a greater fall, and erosion went on much more rapidly over the whole surface of the country. The sources of this tributary of the Idle would be carried back further and further southward, and the longitudinal valley would be gradually extended and lowered until merely a low col separated its head-waters from the slopes of the valley in which the Trent was then running north-eastward to Lincoln.

At this epoch in the history of the Trent, floods must have been of frequent occurrence in this particular portion of its valley, owing to the narrowness of the outlet at Lincoln; and the large extent of ground covered by its ancient gravels between Newark and Lincoln testifies to the width of the area over which its flood-waters were able to spread. Under such conditions, therefore, and on some occasion when a large head of water was accumulated in the Trent valley, it is not unlikely that an overflow would take place by way of the low col leading into the aforesaid tributary of the Idle. Every flood would then deepen the passage until the full stream of the river found it easier to take this course than to maintain its former channel through the Lincoln gap.

The exact situation of this col is of course difficult to fix, though some evidence may be obtained from the disposition of the gravels, when these are completely mapped.

There is also some reason to believe that there has been a slight elevation of the high ground occupied by the outcrop of the Lower Oolites east of the great escarpment in Postglacial times. The valley in which Ancaster lies is a transverse cut through this high ground, and is paved with deposits of sand and gravel, which are continuous with those of the Witham valley north of Grantham; and it appears probable that the Witham passed through this valley at the time when the Trent flowed through the Lincoln valley.

Now, however, a low watershed crosses the Ancaster valley, just west of the town, throwing off the Honington Beck to the west, and the Sleaford Beck to the east; and this watershed occurs in the midst of a broad tract of stratified gravel, which must have been deposited there before the watershed was formed.

Further, the section in the railway-cutting west of Ancaster station shows that the Lower Oolites (Lincolnshire Limestone and Lower Estuarine series) are here bent into a low and broad anti-clinal curve, the axis of which seems to strike nearly due north and south.

It would appear, therefore, that there has been an uplift across this ancient line of drainage in Postglacial lines, causing the Witham to turn westward and take its present course; and the influence of the same uplift, if continued further north, may have contributed to divert the Trent from its original eastward course *viâ* the Lincoln valley.

Whether this, however, was the case or not, the diversion of the Trent could not have been effected unless a course had been already prepared for it by the action of streams in lowering the longitudinal valley south of Gainsborough. In comparing the two instances I described of the diversion of an older stream by the extension of a longitudinal river-valley, the chief difference appears to be this:—In the first case, that of the Steeping and Calceby Becks, it was the upper tributaries of the latter which were diverted into the longitudinal valley; while in the second case it was the main stream of the Trent which was so intercepted and diverted.

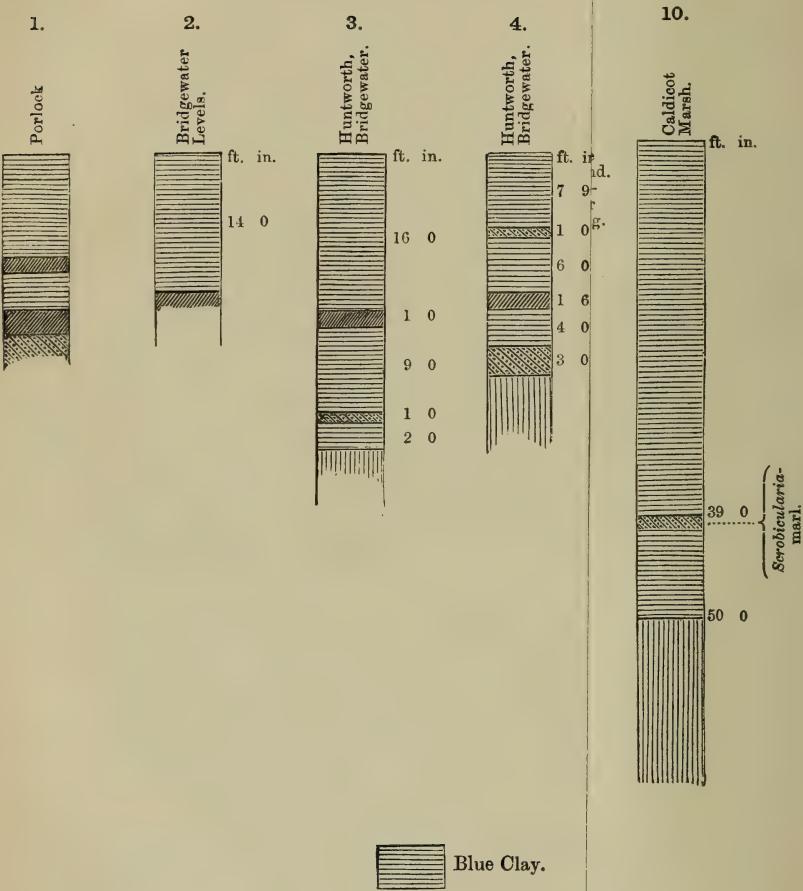
I believe that the principles above enunciated and exemplified will explain the courses of certain other English rivers, and purpose recurring to the subject in a future paper.

#### DISCUSSION.

Mr. EVANS instanced the case of the Waveney and the Little Ouse once flowing from different sources, but now from one near Lopham Ford, the deposit of glacial clay in this instance also forming an element in the case.



Fig





35. *The ESTUARIES of the SEVERN and its TRIBUTARIES; an INQUIRY into the NATURE and ORIGIN of their TIDAL SEDIMENT and ALLUVIAL FLATS.* By Professor W. J. SOLLAS, M.A., F.R.S.E., F.G.S., Fellow of St. John's College, Cambridge. (Read June 6, 1883.)

THE tidal channel of the Severn is notorious for its mud. At high tide it is filled with a sea of turbid water, thick and opaque with tawny-coloured sediment; as the tide ebbs a broad expanse of shining mud flats is revealed fringing the coast; but so like is the water to the mud that, seen from a distance, it is often hard to tell where the sea ends and the shore begins. It is the same with its tributaries, the Wye, the Usk, Ely, and Rhymney on the Welsh side, the Avon, Yeo, Parrot, and others on the English coast.

The source of this mud has been made a subject of much dispute.

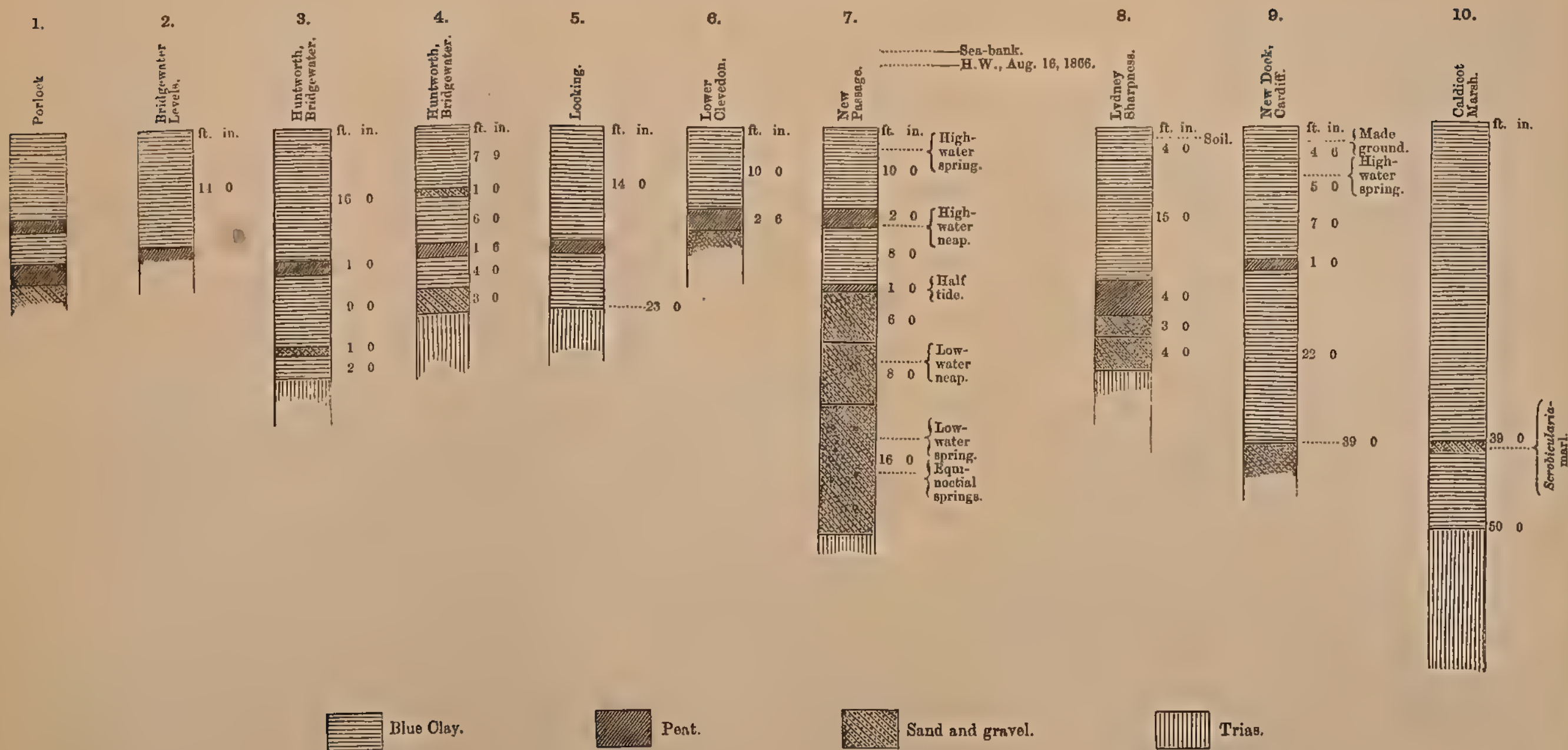
That it is chiefly supplied by the rivers themselves to their respective estuaries might sound to geologists like an obvious truth; but such is certainly not the opinion of those who have most closely inquired into the matter. Engineers like Mr. C. Richardson and Mr. Howard have long been of opinion that the sediment of the tidal Avon is furnished to it by the Severn; the like is asserted of the Parrot, and I do not think one stands in any fear of contradiction when stating as a general truth that all the estuaries opening into the Severn derive their mud at least immediately from the main channel. This being so, whence then has the Severn obtained it? The answers given to this inquiry by engineers are various: some attribute it to the sea, meaning, it is to be supposed, the mouth of the Bristol Channel; some to the mud shoals of the estuary; some to its bordering cliffs; and others to the fresh water of its tributary rivers.

There is, no doubt, truth in all these opinions, and the only mistake lies in regarding them as mutually exclusive, or in assigning to any one source a larger share than its due.

With regard to the fluctuating mud-banks in the channel, they have been deposited by the tidal water, and will in time be washed away again, and redeposited, and so on again and again. However obviously a source of mud, they are certainly a long way from being an ultimate source, and nothing is to be gained from their further consideration.

With regard to the relative share contributed by the remaining agents, the view which geologists would take on general grounds is no doubt correct; the rivers which discharge into the Severn estuary, draining, as they do, a catchment basin of 9193 square miles, are the chief sources of supply; but that much is produced by the waves which wash the shores of the estuary, assisted, as they are, by sub-aerial agents, is also clear, and to this the cliffs of Penarth, Aust, and Portishead bear striking testimony. That the distant sea has contributed anything at all is not an idea likely at first sight to find much

Figs. 1-10.—Sections of Alluvial Deposits of the Estuary of the Severn.





favour ; yet I shall hope to show that it is one, at all events, supported by evidence of considerable weight.

When, however, all these sources have been admitted as genuine, there still remains one difficulty which has much exercised the minds of many painstaking observers. The Severn and its tributaries are not, except when flooded, very muddy rivers ; the wash of the cliffs is not, as a rule, excessive ; the sea, if it furnishes anything, certainly cannot furnish much ; and yet the vast body of estuarine water which extends from Weston to Portishead is never otherwise than a sea of more or less diluted mud\*.

The explanation of this lies in the fact that the water in the tidal portion of the Severn channel flows up and down twice daily at the rate of from 6 to 12 miles an hour, a velocity much greater than that required to move along large boulders of rocks. Water moving at this rate is far more likely to denude than to deposit material ; and indeed in certain parts of the Severn it is, by scouring along great masses of boulders, deepening the channel ; and to its past action in this way the deep water known as the "shoots" is attributed by Mr. Richardson.

In this rapidly moving body of water, the direction of which is reversed twice daily, the mud discharged by the rivers and washed from the beach accumulates, and from it sediment is supplied to all the tributary estuaries during flood tide ; a sufficient diminution in the velocity of the current will of course be marked by the subsidence of sediment, and when the velocity sinks to zero sedimentation is copious. Such a cessation of movement appears to take place in the Avon during ebb tide, as Mr. W. R. Browne has well shown by a series of experiments made with an ingenious current-meter devised by my colleague Prof. H. S. Shaw. I give Mr. Browne's results in his own words † :—"In ordinary tidal channels, such as the Avon below Bristol, the course of events during an ebb seems to be as follows. At first the slope of the surface is exceedingly small (in the Avon it was about  $1\frac{1}{2}$  foot in  $7\frac{1}{4}$  miles), and, while the velocity at the surface is considerable, it diminishes rapidly from thence downwards, and at some distance from the bottom becomes *nil*. This continues for about two thirds of the ebb, the surface-velocity increasing up to a certain point, and then becoming nearly constant. During all this time not only is no scour going on at the bottom, but, if the waters be muddy, an actual deposition of silt is taking place. At this time, after about two thirds of the ebb, the water has fallen about three quarters of its total height, the slope of the surface has considerably increased, and the conditions approximate to those of an ordinary river. The bottom layers of the water then spring suddenly into motion, the surface-velocity diminishes steadily as the tidal waters disappear, until it assumes the normal rate of the low-water flow.

\* This expression is doubtless somewhat too strong. Actual experiments made in 1837, showed the presence of  $\frac{1}{28\frac{1}{2}}$  part, by weight, of sediment in the tidal water opposite Avonmouth, and  $\frac{1}{3\frac{1}{2}}$  part on the opposite coast (B. A. Rep. Trans. of Sections, p. 76). Fresh determinations are doubtless needed.

† Proc. Inst. Civil Engineers, vol. lxvi. p. 1. To this valuable paper is appended the report of a no less valuable discussion.



During this period a scour of the bottom is of course going on ; but, as this velocity is not much higher than in the subsequent period of low-water flow, the rate of scour will not be much greater ; and the actual scour will be insufficient to compensate for the amount of deposit from the tidal waters which has taken place, not only during the period of high water, but also during the first two thirds of the ebb. It must follow therefore that the scouring effect of the tide is little or nothing, and the observed incapacity of tidal flows to sweep away the silt they have deposited is amply and satisfactorily explained."

Though some of the silt in the tidal water may, as thus explained, stay behind in the estuaries themselves, yet the greater portion is carried seaward ; for, in addition to the oscillating movement of the tidal water, there is of course a discharge into the sea of as much water as the rivers bring down into the estuary, and this is probably accompanied by a transference to the sea of a corresponding quantity of suspended mud, so that the final resting-place of the sediment of the Severn is situated some distance out to sea. But between this quiet spot and the margin where the Severn meets the tide the sediment is carried up and down, far and frequently, and it is not till many journeys are accomplished that it comes permanently to rest.

Thus in the waters of the Severn estuary there is a storage of suspended sediment, the accumulation of as many days, or weeks, or months as are occupied in its wanderings to and fro. The accumulation is always being diminished by withdrawals seaward, and as constantly renewed by fresh accessions provided by the denudation of the land.

This is the whole explanation of the remarkable turbidity of the estuarine Severn.

*Microscopical Examination of the Tidal Mud.*—With a view to throwing some additional light on the sources of the Severn silt, I have examined under the microscope specimens from a large number of localities on both sides of the Severn, including its tributaries ; thus Weston-super-mare, Penarth, Portishead, Avonmouth, and Gloucester are sufficiently far apart for the sampling of the Severn itself ; Bridgewater served for the Parrot, Rhymney Bridge (near Cardiff) for the Rhymney, Newport, Mon., for the Usk, Chepstow for the Wye, and Rownham Ferry, near Bristol, for the Avon.

The character of the mud from all these places is so similar that a description of one would serve for all the rest.

The ingredients may be classed as mineral and organic ; the former consist of :—a variable quantity of fine argillaceous granules, small angular fragments of colourless transparent quartz containing numerous minute included cavities, a few similar fragments of flint, siliceous fragments of a glauconitic green colour, minute crystals of quartz of the ordinary form, minute prisms of tourmaline, highly dichroic and similar in form to macroscopic prisms of schorl, and minute rhombohedra of calcite.

The organic constituents are siliceous and calcareous, the latter include :—coccoliths and rarely coccospheres, both of the ordinary

cyatholith type so common in adjacent seas and in the Atlantic ooze; Foraminifera of various species, such as *Miliola*, which are usually small and scarcely if at all distinguishable from the young of *Miliola obesa* figured by Max Schultze (Org. der Polythalamien, plate ii.), *Textularia*, probably *T. variabilis*, but more than one species is present, *Nonionina crassula*, *Polystomella umbilicata*, *Rotalia*, sp., *Spirillina*, sp., and others, including some finely arenaceous forms; spicules of Alcyonaria rarely; fragments of Echinoderm skeletons and minute spines; and triradiate spicules of Calcisponges, probably derived from *Sycandra ciliata* and *S. compressa*. Most of the Foraminifera are quite empty, glassy and transparent; but some contain a brownish soft granular material; and in one instance a small Rotaline form was observed partially replaced by pyrites.

The siliceous constituents are chiefly sponge-spicules, very rarely Radiolaria, and a variable quantity of Diatoms. The sponge-spicules are of very various forms and sizes. They include:—simple acerates, some smooth like those of *Amorphina panicea*, others entirely microspined, like those of *Hymedesmia inflata*; simple acuates; acuates with a pin-like head, some of which may have been derived from *Cliona*, and others from *Suberitis ficus* and other Suberites; small acuates entirely microspined, similar to the echinating spicules of some species of *Dictyocylindrus*, and others similar to the smaller acuates of *Microciona armata*; large pin-headed acuates with the head only spined, similar to the large spicules of *Microciona armata*; large trifid spicules with simple projecting rays, probably derived from a Geodine sponge; and others with expanded bifid rays somewhat similar to those of *Eccionema ponderosa*; Geodine globates and stellates of *Tethya lyncurium*; in one instance a bihamate, such as might have come from *Halichondria inornatus*. Though many of the spicules are entire, the majority are mere fragments, little rod-like cylinders of very various lengths and thickness, perforated by an enlarged axial canal.

From the inorganic constituents but little is to be learned, least of all from the mud: the fragments of quartz are more interesting, since precisely similar fragments abound in the tributary rivers of the estuary, viz., the Severn, Stratford Avon, and Bristol Avon; similar quartz grains, however, are common in the cliffs of Aust.

By far the most remarkable constituents are the remains of organisms; for these are all marine, and yet occur on the banks of rivers at a great distance from a truly marine area.

Past experience has shown me that rivers sometimes bear to the sea considerable quantities of undissolved calcareous matter derived from the formations through which they flow; thus coccoliths and Foraminifera derived from the denudation of the chalk are always to be found floating in the water of the river Cam near Cambridge, and have in past times been deposited along with other sediment in its gravels, as, for instance, near Barnwell, a fact which has led me to suggest\* that the cornstones of the Old Red Sandstone have

\* Quart. Journ. Geol. Soc. vol. xxxv. p. 492.

probably been formed from mechanical sediments derived from the denudation of Cambrian limestones, such as those of Bala and Hirnant.

Hence in discussing the source of these constituents of the Severn ooze, three possibilities present themselves for investigation. The marine organisms may have been derived (i) from the older formations through which the Severn and its tributaries flow; or (ii) from the alluvial flats of its estuary; or finally (iii) from the coast of the Bristol Channel, where under true marine conditions organisms which could furnish such structures as we have described are known to flourish abundantly.

To commence with the first suggestion. Although it may seem improbable that the older formations should have furnished any considerable portion of the organic remains, yet to set the matter at rest, I visited the Severn and two of its tributaries, the Bristol and Stratford Avons (which seemed most likely sources, since they flow through Secondary formations), and obtained from them samples of mud at points above the limit of tidal influence. The locality selected on the Severn was about two miles above Worcester; on the Stratford Avon at Defford; and on the Bristol Avon, at Saltford and Keynsham. In every sample sponge-spicules occurred pretty freely, but a close examination proved to a certainty that these were all fluviatile, and not marine; they not only agreed in size and shape with spicules of *Spongilla fluviatilis*, but were sometimes associated with the characteristic spicules of the statoblasts, or even with the entire statoblast itself. This observation was interesting, as showing not only the entire absence of marine forms, but also a wider distribution of freshwater sponge-spicules than I had previously supposed. Not only were marine spicules absent, but there were also no traces of Foraminifera, coccoliths, or any other marine remains, such as are present in the tidal silt. Thus the rivers, as a possible source of these remains, are eliminated.

The chief constituents of the silt at Worcester are fragments of quartz with some little flint; at Defford similar fragments, together with rhombohedra of calcite, both separate and aggregated into masses like sugar candy, as well as Diatoms and spicules of *Spongilla fluviatilis*; at Saltford also fragments of quartz containing minute cavities, minute crystals of quartz, some flint, occasional flakes of mica, many spicules of *Spongilla fluviatilis*, and Diatoms.

We have next to inquire into the second possibility, *i. e.*, the chance of derivation from the ancient alluvium of the Severn; this is not so readily dismissed. The blue silt of the Severn alluvium is strikingly similar in all its characters to the modern ooze; it consists of a similar admixture of mud and angular siliceous fragments; while marine sponge-spicules, Foraminifera, coccoliths, and other marine remains similar to those of the modern silt, are universally disseminated throughout its mass. They occur in its upper portion where it forms the shore of the estuary, and on the surface of fields where it is tilled; and they are just as plentiful deeper down, 15 or 20 feet below the surface, as in the new cutting for the railway to the Severn tunnel,





or even over 30 feet below, as in the new docks at Cardiff. Distant from the sea, as at Locking, 3 miles inland, they are not less abundant than on its shores; and it is a point worth passing mention that the alluvium on which a part of the city of Bristol stands contains them equally with the rest.

Thus, if the alluvium undergoes any considerable denudation, and so supplies sediment to the tidal waters, it cannot fail to furnish them at the same time with sponge-spicules and those other organic remains already described.

It is important then to inquire (i) whether the alluvium is undergoing extensive denudation, and (ii) whether the organic débris in the recent silt has all those characters which it should possess if it is thence derived.

The alluvium is certainly being denuded, and that partly by the numerous small "renes" and "pills" which flow through it, and partly by the waves which fall along the coast. It has also been suggested that the scour of tidal waters must act powerfully on any alluvial tracts which may possibly form a part of the floor of the estuary. Whether these exist or not I do not know, and have no evidence for or against them. The denudation effected by the waves must be very inconsiderable, since a stone sea-wall extends along the greater part of the margin of the alluvium, and where it is absent, denudation does not as a rule take place; if it did, a stone wall would have been built for protection. To this rule there is, however, at least one exception known to me. This is along the tract just north of Avonmouth: here the alluvial flat is cut into a line of low cliffs, which, owing to the tenacious homogeneous character of the deposit, present a curved profile of remarkable regularity; a gentle slope at the base curves upwards till it attains verticality just above middle height, and there bends outwards to end beneath a projecting cornice of grassy turf.

The streams or "pills" certainly have some effect, first undermining their banks, and then washing the mud resulting away out to the tide-way.

We may then conclude that a not inconsiderable, but undetermined, quantity of sediment containing minute fossils is contributed by the alluvial deposits to the estuarine water. It by no means follows, however, that the whole, or even the majority, of the organic structures found in the estuary owe their origin to this source. To the discussion of this point we next pass.

In the first place, considering that the modern mud of the estuary is furnished chiefly by the river Severn and its tributaries, and only to a small extent by the banks of the estuary itself, one would expect, were these the sole source of the organic remains, to find a much smaller quantity of them, relatively to the mineral constituents, in the modern than in the ancient silt. This, however, is the reverse of being the case; the organic remains are as plentiful in the one as in the other. Since the dilution, if one may so speak, of the ancient by the modern mud has no effect in reducing the relative quantity of organic remains present in the latter, one must conclude that a cer-

tain addition of these constituents is now being made from some other source, in order to maintain the proportion unchanged.

In the next place, it is well known that siliceous sponge-spicules when left to the action of sea-water\* slowly dissolve, the first signs of solution to make their appearance being usually an enlargement of the excessively fine canals which perforate them axially. The calcareous spicules of the *Calcispongiae* are, as one might expect, but to a far greater extent than one would expect, more soluble than siliceous ones, and thus their preservation is exceedingly rare.

The spicules which occur in the alluvium of the Severn, particularly the broken ones, generally give marked evidence of this solution; the canals of whole spicules are frequently, and of fragments always, obviously enlarged. An interesting difference in this respect is to be noticed between the spicules of the superficial alluvium at Avonmouth and that deeper seated, say at about 12 feet from the surface, as in the cutting for the Severn tunnel; those from the latter, having been exposed to solvent action for a much longer time than the former, are traversed by canals from  $\frac{1}{6}$  to  $\frac{1}{2}$  of their diameter, sometimes more, so as to present us with mere shells or husks, though sometimes less; but the canals of those found near the surface are seldom as much as  $\frac{1}{6}$  of the diameter of the spicule, and often less. As, however, it is the superficial alluvium which is now in course of erosion by streams and waves, we may in considering the source of the spicules found in the tidal waters confine our attention exclusively to it†. With respect to the spicules now found in the tidal waters, one may as well state at once that they also show marked signs of solution, not quite to the same extent perhaps as the fragments found in the alluvium, although the difference is very slight. Entire uninjured spicules, untouched by solution, are, on the whole, slightly commoner in the former.

Admitting that there is very little difference in the average size of the canals of the spicules found in the superficial alluvium and those floating about in the estuary, one might still argue that had the latter been derived from the former, they should, making allowance for their additional soaking in the water, present us with larger canals. But this is certainly not the case, the difference, if any, being the other way: and thus one might conclude that the floating spicules have not been washed out of the alluvium. Considering, however, the important conclusions which would follow such an admission, I shall not lay any stress on evidence of such a superfine nature, but prefer to adduce two sets of facts, which have the appearance of bringing the matter to a demonstration. The

\* Salt water is not necessary to this solution, as is shown by the fact that the spicules of *Spongilla* found in river-mud frequently exhibit greatly enlarged canals.

† If, however, tracts of alluvium form part of the bed of the estuary, the tide must by this time have denuded down to the lower deposits, and the spicules derived from them would be those which have undergone extreme solution; and as the spicules of the recent mud do not possess greatly enlarged canals, this source is excluded.

first is that calcareous spicules, which, being more amenable to solution, furnish a much more delicate test, do not occur in the alluvium, or, if so, very rarely, and then as broken and corroded fragments\*; in the recent ooze, on the other hand, as on the mud-banks at Rownham Ferry, they are far from uncommon, frequently entire, even to the points, and always colourless, transparent, and glassy, as though only just shed from a decaying sponge. The next fact is, that at Portishead some spicules very similar to those of *Isodictya cinerea* were found in the sample of mud I had from that place, still closely associated, being entangled together in some kind of organic matter; a fact easily explained if they had only recently been washed away from a dead sponge, but well-nigh impossible of belief if we imagine them to have been washed out of the alluvium, where all animal matter must, one would think, have long since lost its coherence, and certainly its power of holding spicules together during a rough voyage.

After a close examination of the recent silt and the ancient alluvium, and by reason of the facts just adduced, I feel convinced that the majority of the organic remains in the tidal waters have been brought from a different source from that offered by the alluvium. This is a conclusion to which, on general grounds, one would naturally incline; for the alluvium has, according to all evidence, been formed under just such conditions as prevail in the estuary at the present day, making some allowance for slight differences in level; and the presence of spicules and other organic débris in it cannot be accounted for in a different manner from that adopted for the more recent deposits.

Having estimated the influence of the alluvium, we next turn to the third possible, and the chief, sources of the organisms in the modern silt; this in all probability will likewise have been the source of the fossils in the alluvium.

So far as can be determined from a careful examination of the coast, sponges do not grow anywhere so near Bristol on this side of the Channel as Portishead and Weston; Lynton, which is about 60 miles away, is the nearest possible locality; while Ilfracombe, about 15 miles further west, is well known as a rich collecting-ground for both siliceous and calcareous sponges and a host of other marine forms, including Sea Urchins and Starfish, which might well furnish the Echinoderm network and spines so frequent in the ooze. On the other side of the Channel one would need to go to Bridgend before meeting with much in the way of shore life, and I doubt, after a hasty visit to that locality, whether much would be found there; a good deal farther west is Tenby, and no naturalist needs to be informed of the luxuriant growth of all kinds of marine animals, including sponges, to be met with there.

\* The strength of this argument is impaired by the fact that since writing the paragraph, I have found in the superficial alluvium near Weston-super-Mare, one or two triradiate calcareous spicules scarcely touched by solution. The question of the solubility of calcareous spicules evidently requires further investigation.



Hence it seems probable that the organisms which furnish the sponge-spicules, tests of Foraminifera, spines and other skeletal fragments of Echinodermata, and the rest, have their home along the coast of the Bristol Channel, from Ilfracombe to Lynmouth on the one side, and from Tenby for an unknown distance eastwards on the other; thence they or their débris, as they perish and decay, are swept away by the tidal current, which rushes up the Severn at the rate of from 6 to 12 miles an hour, and are so distributed both along its shores, even as far north as Gloucester, and to every tributary estuary which opens into it. On these shores, so remote from their source, some of these organic fragments find a permanent resting-place, and thus far inland we discover along a river-bank deposits containing marine remains. But those which stay are few compared to those which are washed away again and carried out to sea, there to be deposited in marine mud-banks, probably not far from their original home.

As now, so in the past, the same process was in progress; but deposition inland took place on a larger scale, for the estuary of the Severn has for so long a time maintained unchanged its present elevation relatively to the sea-level that deposition along its banks is now exceptional and rare. Its alluvial flats are already built up, and are seldom added to; but in its main outlines the process by which they were formed is that which we witness at the present day.

*The Alluvial Flats.*—The great difference in conditions which obtained during the formation of the alluvial flats was a difference in level relatively to the sea. I here present a series of sections, some new, some borrowed from older sources, which will serve to illustrate the general structure of these plains (figs. 1–10, p. 611).

No. 1, Porlock, is constructed from Mr. Godwin-Austen's well-known paper (Quart. Journ. Geol. Soc. vol. xxii. p. 3). The lower bed of peat marks an old forest-growth; the upper peat-bed contains remains of the yellow Iris, a plant which appears to be common in all the peat-beds of the alluvium which I have had an opportunity of examining.

No. 2, Bridgewater levels, is from Buckland and Conybeare (Trans. Geol. Soc. 2nd ser. vol. i. p. 310).

No. 3, Huntworth, Bridgewater, is by W. Baker (Trans. Somerset Archæol. & Nat. Hist. Soc. vol. i. p. 126).

In the gravel-bed near the base remains of pottery are said to have been found; the peat is in two layers, a point worth noticing, since the upper part in No. 7 (New Passage) also exhibits in places a division into two layers, thus suggesting the occurrence of some general change affecting the whole margin of the estuary, probably a double cessation of depression.

No. 4, Huntworth, Bridgewater, is by Mr. Poole (Quart. Journ. Geol. Soc. vol. xx. p. 118).

The bed of gravel, nearly 8 feet from the surface, is interesting, as it appears to emphasize a change which affected the estuary generally, but is elsewhere not so well marked.



No. 5 is a section of a well now being sunk by the Psychical Society, close to the village of Locking, Weston-super-Mare.

The uppermost half of the 14 feet of blue clay above the peat contains less argillaceous matter, and a larger proportion of angular siliceous fragments, than that below, which is also characterized by containing a good deal of decaying vegetable matter. The peat consists of various plant-remains, including leaves and roots of yellow flags and spores and mycelia of fungi, while its upper surface is strewn with trunks and branches of trees, oak, fir, and birch being the chief. The fir still retains its bark, and the heartwood, when cut, is often found to have preserved its original colour. Some of the wood has been bored by some kind of beetle. The peat is remarkably free from intermixture with mineral sediment, a grain or two of angular sand, a sponge-spicule, and a Foraminifer here and there being all that I could find in a specimen appropriately prepared for microscopic examination. In one of my slides the leg of some species of insect is displayed. The clay immediately beneath the peat is much more argillaceous than that above, and of a darker blue colour, attributable probably to the influence of decaying vegetable matter. Sponge-spicules and Foraminifera, however, are common in the sandy, sediment that remains after washing away the argillaceous matter of the clay. At 20 feet from the surface the clay becomes far more sandy and, as a loose blackish sandy clay, extends down to 23 feet, where it rests on a surface of red clay. This red clay closely resembles that of the Trias. It is, however, penetrated by thin fibres of vegetable matter, apparently rootlets, as far down as it has been followed, *i. e.* to 29 feet; if these fibres are those of small plants, as the absence of stumps of trees would suggest, it would seem to follow that the clay cannot be Triassic, and hence one feels a certain amount of doubt as to the age of the red clay in the other sections, where we have regarded it as Triassic.

No. 6, Lower Clevedon, is after Mackintosh (Quart. Journ. Geol. Soc. vol. xxiv. p. 283). This is interesting as showing peat at the same depth below the surface as the upper peat in No. 7.

No. 7. This is a section of a shaft sunk preparatory to beginning the cutting for the new railway, which is to run through the Severn Tunnel; I am indebted for it to the kindness of the Engineer of the Tunnel, Mr. C. Richardson. A similar section, not quite so detailed, appears in a valuable paper by my friend and former pupil Mr. Evan D. Jones, Assistant Engineer of the Tunnel (Proc. Geol. Assoc. vol. vii. no. 6, fig. 4, section 6).

The upper six feet of the blue clay above the peat are (like the upper part of this clay at Locking) fuller of angular siliceous fragments than the rest below; and the lower three feet are not only more argillaceous, but charged with fragments of black and decaying vegetable matter. In association with this vegetable matter we find, and not only here, but also at Cardiff and Locking, abundant spherules, separate and aggregated, of iron pyrites. These

spherules are precisely similar to those occurring in ancient sediments, particularly limestones; they are described in my paper on the Silurian district near Cardiff (Quart. Journ. Geol. Soc. vol. xxxv. p. 504). The direct connexion of the pyrites with the vegetable matter is beautifully shown by their frequent occurrence within the cells of vegetable tissue, where they may be seen occupying the place of the departed protoplasm, and surrounded on all sides by the persistent cellulose cell-wall.

The clay below the first peat is not yet clearly exposed in this cutting. I have so far been able to examine it sufficiently to state that it contains organic remains like those of the upper clay.

The sand, six feet in thickness, is of a greenish blue colour and consists of fragments of colourless quartz, with included cavities and microliths, green grains, and numerous shelly fragments which give it a white-speckled appearance. The most noticeable organic constituents are abundant fragments of some species of Polyzoa; besides these are many chips of Lamellibranch shells, amongst which I noticed a small broken *Avicula*, Foraminifera, spines of Echinoderms, and sponge-spicules.

The lower bed of peat is not yet exposed in the cutting.

The lowest gravel consists of rolled pebbles, angular and subangular blocks of Millstone Grit, vein-quartz, Mountain Limestone, and it may be of other material. Some of the blocks are more than a cubic foot in size, and one subangular fragment of Mountain Limestone was found well smoothed and striated as if by ice.

No. 8 is taken from a paper read by Mr. W. C. Lucy, before the Cotteswold Club, March 6th, 1873. The blue clay is stated to have yielded, at from four to six feet from the surface, nests of *Tellina solidula*, a shell which abounds on some parts of the shores of the estuary at the present day. The peat contained many trunks of trees, chiefly oak, alder, beech, and hazel; some of the oaks were of great size.

No. 9 is a section obtained in excavating the New Docks at Cardiff. I have to express my best thanks for it to my friend Mr. John Storrie, Curator of the Cardiff Museum, who has not only generously sent me full information concerning it, but specimens for examination.

Below  $4\frac{1}{2}$  feet of made ground is blue clay, twelve feet thick, the upper five feet full of Foraminifera, the lower seven feet charged with disseminated vegetable matter, but still containing marine organisms. Next below is peat, from six to eighteen inches thick; of this I trust that Mr. Storrie, with his extensive botanical knowledge, will furnish us with fuller information at some future time. It is remarkably uncontaminated by mineral sediment, if I may judge from the specimen in my possession; only a few grains of angular sand, and some sponge-spicules and Foraminifera occur in it.

Below the peat is 22 feet more of blue clay, in its upper part containing fewer Foraminifera than that above the peat, and many of these are pyritized; in its lower part are still fewer Foraminifera, but many examples of *Scrobicularia piperata*. It is interesting to

find here a *Scrobicularia*-clay, occurring at the same depth as in the shaft at Caldicot, near Portskewet, which is about nineteen miles further north. The clay rests on gravel consisting of Millstone-grit pebbles.

No. 10 is taken from Mr. Evan D. Jones's paper (*loc. cit.*); it was obtained in sinking a shaft through Caldicot Marsh near Portskewet. In Mr. Jones's paper the section has slipped too near the datum-line in the figure; it should be raised till the surface of the clay is on the same level as that of no. 6. fig. 4. The *Scrobicularia*-marl which occurred in this section is of yellowish-grey colour, and is characterized by an admixture of freshwater and brackish-water shells such as *Limnea*, *Planorbis*, *Scrobicularia piperata*, and *Cardium edule*. Diatoms are common in it, and also remains of *Chara*. It presents a striking contrast in colour and composition to the rest of the alluvium.

The foregoing material enables us to classify the alluvial deposits in the following manner:—

- |                        |   |  |
|------------------------|---|--|
| Zone 1. Upper clay.    | { | a. More sandy zone, 5 to 7 feet.                               |
|                        |   | b. More argillaceous zone, with disseminated vegetable matter. |
|                        |   | Upper peat.  |
| Zone 2. Lower clay     |   |  |
|                        |   | Lower peat.  |
| Zone 3. Sands and mud. |   |  |
|                        |   | Gravel.  |

With the gravel we have not now to do; the presence in it of glacial stones is very suggestive; but, as further information with regard to it will be forthcoming as the works of the Severn Tunnel progress, we may defer for the present the question of its formation. The sand is evidently a marine or tidal deposit, like the blue clay, from which it differs chiefly in containing no argillaceous sediment or scarcely any. It is not a constant deposit, and may possibly be explained by local current-action, though the gradual succession from coarse through fine gravel to this sand in ascending order seems to require some more general explanation. The fact that it is entirely absent at Caldicot on the opposite side of the river, but is represented there by ordinary blue silt, is in favour of merely local action. The mud below this gravel in Section 3 is on this horizon; its upper part, on which the gravel reposes, is penetrated by rootlets, indicating a land surface.

There is a difficulty, when only one layer of peat is present in a section, in determining whether it is upper or lower; we may safely regard the lower bed at Porlock, and at New Passage, and the single bed at Lydney as lower peat; the remaining peat-beds are probably upper.

The lower peat must evidently have accumulated at a time when the relative level of land and sea was different from that of the present day. At New Passage, for instance, it lies at half-tide level, and would have been, under existing conditions, always submerged for one half the day. An elevation of twenty feet, however, is all that is



required to bring the layer of peat up to the same level as that of the existing surface of the ground; and more than this cannot, I think, well be allowed, for the tidal deposits lying conformably above and below both beds of peat seem to point to a simple movement of depression interrupted by occasional pauses. The tidal mud beneath the peat proves that during its formation the margin of the land was below water, just as surely as the layer of peat proves that during its formation it was above. We can account for the silt on the theory that it was a case of "deposition during depression;" and we can also account for the peat by supposing that the downward movement ceased for an interval; during which deposition continued and led to the silting-up of the creeks and bays of the estuary to above the high-water level of ordinary spring tides: extraordinary spring tides would raise the level somewhat above "high-water spring" mark; and a marsh-growth would raise it somewhat higher still. The cleansing of muddy water on passing through the reedy margin of a marsh has been alluded to by Sir Charles Lyell, and may be invoked here to account for the general purity of the peat, which, nevertheless, does contain some sponge-spicules, Foraminifera, and sand-grains, though few.

After a long pause, during which the lower peat, with its associated remains of forests, was formed, subsidence set in again, and the lower blue clay gradually accumulated over the layer of vegetable matter.

Another interval of rest succeeded, during which a new alluvial surface rose above the tide, and the upper bed of peat was produced; again the movement of depression was renewed, and apparently not uniformly, since the lower part of the upper clay contains scattered fragments of plants which were probably derived from some exposed portion of the peat, which the waves ploughed to pieces and distributed far and wide. During the continuance of the depression the upper gravel bed at Bridgewater was laid down, probably through local current-action due to the change in the configuration of the estuary consequent on its depression. Finally, the upper part of the blue clay was deposited; and this is more arenaceous than the lower part of the same deposit, because the continued depression had brought the sea nearer the area of deposition. The tidal waters, as the land sunk, extended further and further up the estuary and its tributaries; and, meeting the upland waters further inland, sooner received their supplies of sediment. But it was from these muddy tidal waters that the silt of the alluvial flats was supplied, and thus, the source of sediment being shifted nearer the area of deposition, we have, according to a well-understood rule, coarser succeeding to finer sediments.

Thus then we explain the origin of the alluvial tracts of the Severn. Save for differences of level, they have been formed in the same way as tidal deposits are accumulating at the present day; in the past as in the present the tidal waters rose and fell in the estuary, transporting with them sediment of a double origin, the joint product of the land and sea.



*The Sewage Question.*—The important bearing of these observations on the conclusions of modern engineers as to the fate of sewage poured into tidal waters need scarcely be pointed out. It is certain that the fæcal residues which destroy the purity of our streams, and serve as breeding-matter for disease-germs, do not obtain at once a safe burial in the sea, but linger with us for days or weeks, or may be for months, wandering with the ceaseless oscillation of the tides; while a part never reaches the sea at all, but is strewn with impartial hand at the foot of every town which the tidal current reaches and defiles.

In conclusion, I desire to offer my best thanks to my friends Messrs. T. J. Ranson of Weston-super-Mare, T. Jones, F.G.S., of Newport, Mon., F. G. Evans and J. Storrie of Cardiff, for their kindness in sending me specimens for examination.

*Note.*—Since writing this paper I have received from my brother Mr. Edgar W. Sollas of London, specimens of mud taken from the banks of the Thames near London Bridge. On examination I find in them characteristic sponge-spicules, Suberitic and others, indicative of marine origin.

#### DISCUSSION.

Prof. BOYD DAWKINS said that he congratulated the author upon the way in which he had dealt with the phenomena which he had brought before the Society. The bearing of his remarks upon the sewage question was very important. The physical change implied by the submarine forest in the area examined by the author, and which Prof. Dawkins had studied for many years, was to be observed all round our coasts where the shore was a shelving one. The forests of oak, yew, and Scotch fir occupy a belt stretching from about Ordnance datum to below low-water mark, and he had identified the short-horned ox, goat, sheep, and hog among the animals discovered in them at various points. Between Porlock and Minehead he and the Rev. W. H. Winwood had found numerous flint chips and flakes. The forests, therefore, were flourishing in the age of the domestic animals, or the Prehistoric period, most probably in the Neolithic stage of that period, and formed a belt extending from our shores to an unknown distance seawards. With regard to the section at Porlock Weir, he could not agree with the author that there was a second bed of peat. It was, as Mr. Godwin-Austen describes it, merely a surface-growth of *Iris*.

Dr. HICKS said that he could quite confirm, from personal observation, the views of the author in regard to the extension westward of the old forests. That the mud went landward instead of seaward was a point with important physical bearings. He remarked upon the distribution of the materials according to their weight and volume.

Mr. WHITAKER said that the paper had an interest from the analogies of the Severn deposits with others of a like kind. He had recently been working near the Wash, the low land bordering which

was formed of material deposited by the up-tide, so that the materials were derived from the Yorkshire coast. The sections of the Severn alluvial flats corresponded with those of the Fenland. He thought it would be better to say that submerged forests occur at the junction of a river with the sea, rather than on a low shelving shore, as stated by Prof. Boyd Dawkins. "Submerged forests" and "peat-beds" were substantially the same phenomenon. It was, however, important to remember that the subsidence need only be slight. He had lately heard some facts with reference to the action of the tide in the Thames:—experiments had been made with floats, and in some cases the floats were found after a fortnight or more to have travelled up the stream; others, however, had slowly descended. It was therefore evident that much remained to be learned about the tides.

Prof. SOLLAS was glad to find that the results of his study of this particular estuary were sufficiently in harmony with Prof. Dawkins's generalizations. He differed, however, in two particulars: the first was with reference to the deposits immediately beneath the peat, which he regarded as not fluvial, but tidal or marine; and the second as to the extent of the submergence which had taken place subsequent to the formation of the peat; he thought the land need not have stood more than 20 feet higher than at present for the growth of the first peat-bed, and 10 feet for the second.

36. NOTES on the GEOLOGY of the TROAD. *A brief SUMMARY of the RESULTS derived from the OBSERVATIONS made in connexion with the ASSOS (U.S.) EXPEDITION.* By J. S. DILLER, Esq., Geologist to the Expedition. Communicated, with Notes, by W. Topley, Esq., F.G.S. (Read June 6, 1883.)

THE terranes of the Troadic peninsula comprise a variety of stratified and massive or eruptive rocks. The former, excepting the most recent deposits, which are not considered in this connexion, may be divided into three groups according to their mineralogical conditions and geological age.

The most ancient group is highly crystalline and, in all probability, belongs to the so-called mica-schist zone of the "Grundgebirge" or Archæan formation.

The youngest group, embracing the Miocene and Pliocene Tertiary deposits, is, at least in part, well characterized by its fossils.

The middle group is defined by the widely separated limits of the other two groups. It embraces rocks which may be Palæozoic or Prepalæozoic, as well as others which are probably of Cretaceous and Eocene age.

*Crystalline Schists.*—The crystalline schists have their greatest development in Mount Ida, of which they form almost the entire mass. They are of many varieties, all conformably interstratified, as if belonging to the same great terrane.

True gneisses are not abundant, and occur chiefly upon the north side of Mount Ida, under such conditions that they appear to overlie the schistose rocks. In Hadji-eulduren-dagh the mica is in large part replaced by hornblende, so that the gneiss has a dioritic aspect.

In the schistose rocks (chiefly amphibolites) hornblende is one of the most widely distributed and abundant minerals. It generally appears as actinolite, and not unfrequently constitutes almost the whole of the rock in which it occurs. With amphibole are associated, besides felspar, at times more or less quartz, epidote, magnetite, titanite, and rutile. True mica-schists are of less common occurrence, interstratified with the amphibolites.

Near the centre of Mount Ida the oldest rocks crop out, and among them is talc-schist, which, by the gradual addition of olivine, passes into small lenticular masses composed almost exclusively of the latter mineral. According to the nomenclature of Brögger this rock should be called olivine-schist. By alteration it gives rise to serpentine, with the characteristic reticulated structure which ever marks the serpentine derived from olivine. Occasionally the fibrous serpentine forms veins of considerable size in the adjacent rocks.

The olivine-schist, where purest, has no schistose structure. The passage from talc-schist, in which no olivine occurs, to that composed almost entirely of olivine, takes place sometimes within a short distance. The chief mass of the rock, however, is a middle stage





between the two extremes, having a distinctly schistose structure, and being composed for the most part of olivine and talc, besides considerable quantities of pyroxene as well as other minerals not yet determined.

At various intervals throughout the zone of schistose rocks occur rather coarsely crystalline white limestones.

The structure of Mount Ida is a comparatively simple anticlinal, with so short an axis extending east and west that the upper portion of the mountain is approximately a dome.

The highly crystalline stratified rocks are, perhaps, the chief topographical determinants of that region. Their position and distribution indicate that, in the early stages of its development, the peninsula of the Troad was represented by several islands which furnished much of the detritus for subsequent formations.

*Intermediate Zone.*—The rocks of the middle zone are for the most part semicrystalline limestones, a very ferruginous quartzite, together with greenish, somewhat schistose, rocks, and others which are, macroscopically, like argillites, but contain too large a proportion of quartz.

The limestone is generally compact, grey or reddish-coloured, very like the Cretaceous (according to Prof. Neumayr) in the Acropolis at Athens, and has often large quantities of silica so irregularly distributed as to produce a very rough weathered surface, like the Cretaceous limestone west of Smyrna. This limestone is found chiefly about the base of Mt. Ida, at Edremit (Adramyti), near Dikelee-dagh and Chaly-dagh, also between Quayalar and Ahmadja and several kilometres south-west of Ilèsfagy. At Cojèkia-dagh (the spur of Dikelee-dagh on which stand the remains of the ancient Gargara) it is peculiar in containing many small acicular quartz crystals. The ferruginous quartzite was observed in one locality only.

The greenish, somewhat schistose rocks, with sandstones of the same colour, near Ahmadja, as west of Smyrna, overlie the limestone. The Cretaceous age of the limestone at the locality last named appears to be quite definitely determined by the observations of Strickland, Tchihatcheff, and Spratt; but the age of that near Ahmadja is yet uncertain. Concerning the single fossil which has been found in it, Prof. Neumayr writes, it is a *Rhynchonella*, which is so widely distributed that it cannot be used as a certain means of determining the age of the strata in which it occurs; but the limestone is probably Cretaceous.

That these rocks are younger than those of the mica-schist zone is indicated not only by the fact that they contain fossils and are less crystalline than that group, but also by the fact that they are made up of sediments derived from the crystalline schists. On the other hand that they are, at least in part, old rocks is shown by the contact-zone produced in them by the quartz-diorite.

In 1881 Mr. Frank Calvert, American Consul at the Dardanelles, discovered undoubtedly Eocene fossils (Nummulites determined by Prof. Neumayr) at several places in the Troadic peninsula outside

of the region visited by the writer. The same rocks in all probability occur also in the southern Troad; but until further investigations are made, their existence must be left doubtful.

It seems probable therefore that in the Intermediate Zone there are a number of terranes of different ages. It should be stated in this connexion that the rocks of the southern Troad placed by Tchihatcheff provisionally in the Lower Tertiary are, according to Prof. Neumayr, of more recent origin.

*Tertiary Rocks.*—The third or youngest group of stratified deposits, embracing those which are certainly not older than the Miocene, may be divided into two portions. Geographically they are entirely distinct, and their stratigraphical relations are yet uncertain.

*Marine Series.*—The rocks of the Sarmatic stage of the Miocene, so well exposed at Evenkieui, are now known to border the western coast from the Trojan plain to beyond the mouth of the Touzla, near the promontory of Baba-bournou.

At the site of the ancient Hamaxitos, several kilometres south-west of Kinlahly, the "Mactra-kalk" with its characteristic fossils forms the acropolis. This limestone is undoubtedly of marine origin; and although it has a wide distribution north-eastward toward the Caspian and the Vienna basin, yet it has not been recognized further south-west than the coast of the Troad.

Beneath this limestone, as at Evenkieui, is a great thickness of sand and clay beds, which are underlain by a conglomerate, and probably, at the bottom of the series, by a stratum of red clay. The conglomerate is composed chiefly of fragments of andesites and liparites. Fossils have not been found in these beds near Hamaxitos; but at Evenkieui, according to Calvert and Neumayr, organic remains are not unfrequent, and of a mixed character, indicating that the strata belong, at least in great part, to the Sarmatic stage.

The marine beds which overlie the "Mactra-kalk" are largely developed south of the mouth of the Touzla, and contain great numbers of fossils, among which are many *Ostrea* and Gasteropods.

*Freshwater Series.*—The second portion of the Tertiary deposits occupies a large part of the interior of the Troad, about the great plain of the Menderè, between Eanedeh and Bairamitch, as well as along the southern coast west of Papazly. It has furnished but few fossils, and they are of such a character that its age cannot be determined with certainty; however, according to Prof. Neumayr, who has kindly undertaken the determination of the fossils collected by the expedition, it must be Upper Miocene, Mio-pliocene, or Lower Pliocene. That it is in great part a fresh- or, at most, a slightly brackish-water deposit cannot be doubted. As has already been shown in a preliminary report, where these deposits are described at some length, the basis of the series is a conglomerate in which no fragments of the basalts, andesites, and liparites have been found. It is overlain by a series of shales upon which, between Demirdji-kieui and Narly, rests a puzzling rock regarded by Tchihatcheff as limestone. It is usually pale-yellowish

coloured, soft, light and porous, and generally shows no trace of effervescence in hydrochloric acid. In general appearance it closely resembles an impure siliceous limestone out of which the greater portion of the carbonate of lime has been dissolved. Having a thickness of about one hundred and thirty metres, it becomes the chief topographical determinant of that region, and gives rise to profound gorges and bold escarpments. Throughout the greater portion of the mass it is uniformly fine-grained, but under the microscope it has the structure of a tufa.

The upper beds of the series, consisting of thin freshwater limestones, sandstones, shales, and a large proportion of stratified tufas with conglomerates, have not been seen east of Demiradji-kieuï. The fossils collected were found in this portion of the series and it is evident that the ejection of the andesites began before the deposition of those beds was completed.

Numerous oscillations of the land, as indicated by the varying character of the strata, must have occurred during the Miocene and Pliocene periods; and in all probability these movements were connected with the extrusion of the eruptive rocks so abundant in the region.

*Massive Rocks.*—The massive rocks of the Troad belong in part to those of pre-Tertiary origin; but the greater portion were extruded since the beginning of the Tertiary Period. The older group includes biotite-hornblende-granite, quartz-porphry, quartz-diorite, augite-porphyrity, melaphyre, and serpentine; while the younger group embraces liparites, andesites, augite-andesites, basalts, and nepheline-basalt.

*Older Series.*—The biotite-hornblende-granite occurs in a large mass forming the serrated ridge of Chigri-dagh. It is distinctly younger than the highly crystalline stratified rocks which it penetrates, and is especially interesting from the fact that where it is altered the titanite is changed to anatase. The alteration of titanite and ilmenite to anatase is doubtless a common and widely spread occurrence; but as the crystals of anatase are very small they have generally been overlooked.

The quartz-porphyrityes are chiefly microgranites, and are younger than the biotite-hornblende-granite through which they have been extruded. The dykes in which they occur are comparatively small and do not exercise much influence upon the topographical features of the country.

The quartz-diorites form a number of comparatively small masses about the base of Mount Ida, and are evidently younger than the quartzose argillite of the middle zone of stratified rocks, which, in one case, has been metamorphosed into a cordierite- and andalusite-hornfels. It is to be especially noted that these eruptive rocks do not, as was formerly supposed, enter into the structure of Mount Ida.

The augite-porphyrityes (diabase-porphyrityes) and melaphyres are, so far as is yet known, limited to five outcrops, all lying in a line near the southern coast of the Troad, and which, with the exception of that



between Ahmadja and Quayalar, are not important. The locality just named is of especial interest from the fact that melaphyre was the first rock extruded in that isolated volcanic centre, which is completely surrounded by Tertiary strata; it was followed later at the same place by mica-andesite, hornblende-andesite, augite-andesite, basalt, and late, if not last, by a large outpouring of liparite.

The serpentine in the northern part of the Troad about Kara-dagh has been derived from olivine-enstatite rocks of a truly eruptive nature. The almost entire absence of the characteristic reticulated structure in some of the serpentine from the Kemar valley leaves perhaps some doubt as to the original rock from which it has been derived. As previously stated, the serpentine about the summit of Mount Ida has been derived from olivine-schist, which undoubtedly belongs to the stratified rocks.

*Newer Series.*—Although the ancient eruptive rocks are apparently not nearly so abundant as those of more recent origin, yet they represent very nearly the same range in chemical and mineralogical composition. The granite and quartz-porphyrines have their modern equivalents in the liparites; the quartz-diorites in the mica- and hornblende-andesites; the augite-porphyrines in augite-andesites; the melaphyre in the basalt. However, no equivalents were found for the nepheline-basalts and ancient olivine-enstatite rocks. On the other hand, the syenites and their modern representatives, the trachytes, which were once supposed to be abundant in the Troad, are now known to be at most only sparingly represented.

The liparites occur in various types with many varieties, and are limited to the southern part of the Troad. They appear also south of Molivo on the island of Mitylene, and on the mainland at Sal Mosac south-west of Aivaly. They are generally in a stony condition, but are frequently glassy upon the boundaries, and contain many fragments of the andesites which they penetrated and overflowed. They always occur in dykes, as at Cozlou-dagh, and the great plateau which gives rise to the peculiar drainage of the Touzla river. That some of the liparites were extruded before the deposition of the "Mactra-kalk" is certain; but from the fact that the exact age of the Tertiary deposits in the southern part of the Troad has not been definitely determined, the time of the extrusion of the great mass of the liparites cannot be stated; however, it occurred most likely at the beginning or in the early part of the Pliocene period, when the land was raised above the sea, and the islands converted into a peninsula.

The andesites embrace typical mica-andesites and hornblende-andesites, as well as a great variety in which mica and hornblende occur in nearly equal proportion. These, with augite-andesite, occupy a great area between the Menderè and the southern coast, and, unlike the liparites, they seem to have reached the surface, at least in some cases, through volcanic vents. Not unfrequently they occur in dykes also, and have evidently overflowed a large area of late Tertiary deposits.



Their extrusion along the western coast began before the deposition of the "Mactra-kalk;" and along the southern coast during the formation of the freshwater deposits of that region. Pyroxene is generally a prominent constituent of the andesites, and frequently both rhombic and monoclinic pyroxenes occur together. The former is generally the most abundant, and has, in one case, been proved to be hypersthene. It occurs not only in mica-andesite, as at Assos and Smyrna, but also in the hornblende-andesite north-west of Cozlou-dagh and the augite-andesite west of Sivriji-bournon. Among the great variety of andesites may be mentioned the oldest which flowed from the volcanic crater at Assos. It is a mica-andesite, in the ground-mass of which is a large proportion of apparently primary mica and hæmatite.

The basalts occur in dykes, and, although widely distributed, do not occupy large areas. Along the southern coast of the Troad the basalt is of an andesitic type, and the olivine is occasionally altered to distinctly cleavable pleochroitic serpentine.

The same phenomenon is better developed in the typical nepheline-basalt, which forms the prominent hill of Quaralyly or Sapandja-tepe near the centre of the Troadic peninsula. The basalts and nepheline-basalts are evidently younger than the Tertiary deposits with which they are associated; but the time of their extrusion with reference to that of the other eruptive rocks of the Troad cannot be definitely determined.

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APPENDIX *by* W. TOPLEY, Esq., F.G.S., Geological Survey of England and Wales.

THE foregoing paper is a brief notice of the main results arrived at by Mr. Diller when attached as geologist to the United States Assos Expedition. The field-work extended through two summers, and was supplemented by researches in the petrological laboratory of Heidelberg. A MS. draft of Mr. Diller's geological map (scale 1 : 100,000) was sent to me for the service of the new Geological Map of Europe (and its borders) which is now being prepared by a Committee of the International Geological Congress. The map here given is a reduction of this map; but some of the igneous rocks are grouped, and some other details are necessarily omitted. The heights are inserted from various sources—the English Admiralty Charts, the Austrian Military map, and others.

The map has been prepared in England, and Mr. Diller has not seen a proof; he is therefore not responsible for errors or imperfections therein.

The Assos Expedition was sent out by the Archæological Institute of America, and was under the direction of Mr. J. T. Clarke. The archæological work was mainly confined to Assos, on the southern coast of the Troad, and hence Mr. Diller's work is more complete there than elsewhere. Preliminary Reports have already been

printed\*, but the present paper gives fuller information as regards the classification of the igneous rocks, the result of microscopical examination at Heidelberg. The Reports, on the other hand, deal more fully with the sedimentary rocks and with the physical geography, which are only briefly alluded to here.

The physical geography of the Troad is very closely related to its geological structure. The larger areas of the older crystalline rocks form rugged mountainous regions; that near the west coast north of Touzla rises to a height of nearly 1600 feet, and Kara-dagh to 925 feet. But the grandest mass is that which forms the range of Caz-dagh, the ancient "Ida"—5750 feet. The summits are treeless, but the higher slopes are thickly clothed with pine-woods†; from a mass of crystalline limestone rise the powerful springs which form the head waters of the Menderè (Scamander) and other rivers of the district.

The rocks of the Intermediate Zone form some high land on the western slope of Mt. Ida, attaining a height of 2530 feet at Dikelee-dagh, near the southern coast. The granite of Chigri-dagh also makes high ground, the summit here being 1648 feet.

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Comparatively little has hitherto appeared upon the geology of the Troad, although much has been published upon its topography, especially upon that of the north-eastern portion, where all authorities place the site of Ilium, or Troy. The exact site has long been a matter of dispute; but only two places now claim that honour, Hissarlik and Bounar-bashi. The arguments for or against either site have been largely drawn from questions more or less related to geology, such as the constancy and temperature of springs, changes in the coast-line and in the alluvial plains. Since Dr. Schliemann's excavations at Hissarlik these questions have again been fully gone into, and most authorities now agree that, if any one site is taken, Hissarlik best fulfils the requisite conditions.

The main facts bearing upon this question are now accessible in the pages of Dr. Schliemann's 'Ilios' (1880), where are given many statements by, or extracts from, other writers‡. To this work reference may be made for information upon the numerous topographical and other works relating to the subject. It will suffice here to note those only which more immediately refer to the geology.

\* Report on the Investigations at Assos, 1881, by J. T. Clarke. Papers of the Archæological Institute of America. Classical Series, I. Boston, 1882.—Appendix by J. S. Diller, Geology of Assos, pp. 166–179. Notes upon the Geology of the Troad, pp. 180–215.

A description, by Mr. Diller, of anatase in the granite of Chigri-dagh (as mentioned in the foregoing paper), appears in the 'Neues Jahrbuch,' 1883, p. 187.

† Schliemann (Ilios, p. 70) notes that pines are characteristic of the crystalline rocks east of Hissarlik; they cease on the Tertiary limestones.

‡ See especially R. Virchow, pp. 84–90, 95–99, 673–685; and E. Burnouf, on the changes in the bed of the Scamander, pp. 79–84.

A few brief geological notes on the Troad are given by Dr. E. D. Clarke\*, Professor of Mineralogy at Cambridge; but the first systematic account of the geology is that by Philip Barker Webb, in 1821†.

Lieut. (now Admiral) T. A. B. Spratt, when surveying the northern Troad for the Admiralty, in 1840, with Comm. Graves, produced a topographical map which has not yet been superseded. His purely geological notes on the country were not published till 1857‡; but an account of his researches on the physical features of the country was given by Dr. P. W. Forchhammer in 1843§.

Tchihatcheff's great work on Asia Minor|| describes the rocks of the Troad in detail; but much has been done since then in the study of petrology, and the rocks therein described and marked as "Trachytes" must now be referred to several different classes¶. The same, no doubt, holds true of other districts in Asia Minor. Mr. Diller, in a letter to me, says:—"In the vicinity of Smyrna the rocks formerly marked trachytes should now be marked andesites; and it seems probable, from the hundreds of specimens I have examined microscopically from the Levant, that the trachytes properly so called are scarce in that country."

The Tertiary beds have been studied by Calvert and Neumayr, who describe several new species of *Unio*, *Melania*, *Melanopsis*, &c. from Renkiöi (Arenkiöi) on the shores of the Hellespont\*\*.

Amongst the more recent publications, besides those previously mentioned, the following are important. R. Virchow†† describes

\* 'Travels in various countries of Europe, Asia, and Africa.' 6 vols. 4to. London. Troad in vol. ii., chaps. iv.-vi., 1812.

† 'Osservazioni intorno allo stato antico e presente dell' Agro Trojano.' Biblioteca Italiana, Milan, 1821, pp. 112 and map. Although, as is stated in the title, this memoir is written by a "gentiluomo Inglese," no English translation has appeared. It is best known from the French edition:—"Topographie de la Troade ancienne et moderne." Paris, 1844. It has also appeared in German. A copy of the original, in Italian, is in the library of this Society.

‡ "On the Freshwater Deposits of the Levant," Quart. Journ. Geol. Soc. vol. xiv. pp. 212-219: this paper refers chiefly to the Troad.

§ Journ. R. Geograph. Soc. vol. xii. p. 28; see also 'Topographische und physiographische Beschreibung der Ebene von Troia,' mit einer Karte von T. A. B. Spratt. 8vo. Frankfort: 1850.

|| 'Asie Mineure,' 4 vols. 8vo. Paris. The Physical Geography was published in 1853; the Palæontology (by D'Archiac, Fischer, and De Verneuil) in 1866; the Geology in 1867-69. The Geological Map is on the scale of 1:2,000,000.

¶ The andesite of Assos (the Second Trachyte of Mr. Diller's Assos Report) is the famous "Sarcophagus-stone," which was believed to have the power of rapidly consuming all bodies buried in it.

\*\* "Die jungen Ablagerungen am Hellespont," Denkschr. k.-k. Akad. Wiss. Bd. xl. pp. 357-378, 1880.

For a discussion as to the correlation of the Newer Tertiaries of the Levant &c. see Neumayr, "Ueber den geologischen Bau der Insel Kos und über die Gliederung der jungtertiären Binnenablagerungen des Archipels." (Appendix by M. Hörnes.) Denkschr. k.-k. Akad. Wiss. Bd. xl. pp. 213-314, 1880; also Fuchs, Verhandl. k.-k. geol. Reichsanst., 1881, p. 173.

†† "Reise nach Troja," Verhandl. Berlin Gesellsch. Anthropol. 1879, pp. 204-216; and "Beiträge zur Landeskunde der Troas," Abhandl. k. Akad. Wiss. Berlin, 1879.

the alluvial deposits and changes in the river-course of the plain of Troy, &c.; Frank Calvert\* the supposed changes of the coast-line.

The modern course of the Menderè (Scamander) is on the western side of the plain of Troy, but its ancient bed can still be traced on the eastern side, under the walls of Hissarlik. A similar change is more plainly proved in the Halesian Plain, near the mouth of the Touzla river (the ancient Satnioeis), where a Roman bridge, which once spanned the river, is now 250 yards from it, the old channel having been completely silted up †.

#### DISCUSSION.

Mr. WARINGTON SMYTH remarked on the difficulties he encountered when he travelled in the Troad many years ago. He confirmed the author's views on the general structure of the district, and remarked on the analogies of the volcanic rocks with those of Hungary and the Rhodope to the north and the Katakekaumene to the south.

Admiral SPRATT was also able to confirm the great accuracy of the map, and especially of the divisions of the marine and freshwater Tertiaries. At one point he found the freshwater and marine beds interlacing with each other. He suggested that one of the springs at Bounar-bashi, which he regarded as giving rise to the Scamander, and described by Homer as hot, might have been so in his day, as it issues from a crevice between the limestone and a trap or trachyte dyke.

Mr. TOPLEY stated that the classical names placed on the map were inserted by himself and not on the authority of the author.

\* "Asiatische Küstenlinie des Hellespont," *Zeitschr. für Ethnologie* (Berlin), 1880.

† Another instance of a like nature occurs on the Riviera east of Albenga, where the roadway of a Roman bridge (Ponte Lungo) is now only seven or eight feet above the Alluvium; the river is now west of the old bridge.



# GENERAL INDEX

TO

## THE QUARTERLY JOURNAL

AND

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PROCEEDINGS  
OF THE  
GEOLOGICAL SOCIETY OF LONDON.

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SESSION 1882-83.

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November 1, 1882.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Prof. Louis Lartet, of Toulouse, was elected a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

Specimens of Rocks from Costa Rica (illustrating his paper read on the 24th May, 1882) were presented to the Museum by G. Attwood, Esq., F.G.S.

The following communications were read :—

1. "The Hornblendic and other Schists of the Lizard District, with some Additional Notes on the Serpentine." By Prof. T. G. Bonney, M.A., F.R.S., Sec. G.S.

2. "Notes on some Upper Jurassic *Astrorhizidæ* and *Lituolidæ*." By Dr. Rudolf Häusler, F.G.S.

The following specimens were exhibited :—

Rocks and Rock-sections, exhibited by Prof. T. G. Bonney in illustration of his paper.

Specimens exhibited by Dr. Häusler in illustration of his paper.

November 15, 1882.

Dr. J. GWYN JEFFREYS, F.R.S., Vice-President, in the Chair.

John Edmund Thomas, Esq., Dorset House, Alfred Place, Aberystwyth, and Joseph Williams, Esq., Pant-gwyn House, Holywell, Flintshire, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "The Drift-beds of the North-west of England and North Wales.—Part 2. Their Nature, Stratigraphy, and Distribution." By T. Mellard Reade, Esq., C.E., F.G.S.

2. "On the Evidences of Glacial Action in South Brecknockshire and East Glamorganshire." By T. W. Edgeworth David, Esq. Communicated by Professor J. Prestwich, F.R.S., F.G.S.

The following specimens were exhibited :—

Rock-specimens exhibited by Messrs. Reade and David, in illustration of their papers.

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December 6, 1882.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Charles Bird, Esq., B.A., Mathematical School, Rochester; Enoch Cartwright, Esq., Park View, Wood Green, Wednesbury; Henry Eunson, Esq., C.E., 20 Giles Street, Northampton; William Johnstone, Esq., F.I.C., F.C.S., Athenæum Chambers, Lynn; Henry Liversidge, Esq., Jun., Portington Hall, near Howden; Henry George Lyons, Esq., Royal Military Academy, Woolwich; Joseph Mawson, Esq., St. Ives, Acol Road, West Hampstead, N.W.; Horace W. Monckton, Esq., Hare Court, Temple, E.C., and Junior Carlton Club, W.; Henry Alexander Miers, Esq., B.A., Eden Cottage, Beckenham, Kent; John Postlethwaite, Esq., Eskin Place, Keswick, Cumberland; and Thomas Viccars, Esq., The Public College, Torquay, were elected Fellows of the Society.

The List of Donations to the Library was read.

A case of Rocks, Fossils, &c. from the Department of Salto,



Uruguay, was presented to the Museum by A. K. Mackinnon, Esq., F.G.S.; and four specimens of Mexican Building-stones by F. Newman, Esq., F.G.S.

The following communications were read:—

1. "Note on a Wealden Fern, *Oleandridium (Tæniopteris) Beyrichii*, Schenk, new to Britain." By John E. H. Peyton, Esq., F.G.S.

This fern, figured by Schenk in the 'Palæontographica' (vol. xix. plate xxix. figs. 6, 7), was discovered near Minden, in the North-west German Wealden-beds, and appears to have been hitherto unknown in England. It was first discovered in the Wadhurst Clay ("Tilgate stone" of Mantell) of the cliffs east of Hastings, by Mr. Charles Dawson, of Warrior Terrace, St. Leonards, who has a fine collection of Wealden fossils, and was brought to my notice by Professor Augusto de Linars, of the Valladolid University, who has lately discovered the Wealden in the north of Spain.

This specimen\*, which I have much pleasure in presenting to the Society for their Museum, I found about a fortnight ago, also in our local "blue-stone" from the Wadhurst Clay of the Hastings cliffs.

In connexion with the flora of the Wealden, I may perhaps mention that, besides the ordinary ferns recorded by Mantell, Fitton, Topley, and others, viz. *Lonchopteris Mantelli*, *Sphenopteris gracilis*, *S. Mantelli*, *S. Phillipsii*, *S. Sillimani*, &c., I have been fortunate enough to discover the following North-German forms:—

*Pecopteris Geinitzii*,  
*Pecopteris Murchisoni*,  
*Pterophyllum schaumburgense* (Dunker),

and an undetermined one, which I think is *Sphenopteris Gæpperti*. They all occur in the beds of stone in the Wadhurst Clay, which are locally used for building and road-metal.

2. "On the Mechanics of Glaciers, more especially with relation to their Supposed Power of Excavation." By the Rev. A. Irving, M.A., F.G.S.

A specimen of *Oleandridium Beyrichii*, Schenk, was exhibited, in illustration of Mr. J. E. H. Peyton's communication.

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\* It varies slightly from the one figured by Schenk in the nervures; and the midrib is "herring-boned." It bears a strong resemblance to *Tæniopteris vittata* (Brongn.) of the Trias (Geikie's 'Text-Book of Geology,' fig. 358); compare also *T. scitamineæfolia* (Sternberg), from the Stonesfield beds (Phillips's 'Geology of Oxford,' Diagram xxx. fig. 8).

December 20, 1882.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Percival Fowler, Esq., C.E., 2 Queen Square Place, Westminster, S.W.; Alfred Eley Preston, Esq., C.E., Belle-Vue, Manningham, Bradford, and Exchange, Bradford; and Robert Blake White, Esq., C.E., 23 Anerley Park, S.E., and Medella, U.S. of Colombia, South America, were elected Fellows of the Society.

The List of Donations to the Library was read.

A specimen of *Oleandridium Beyrichii*, Schenk, from the Wadhurst Clay of the Hastings cliffs, was presented to the Museum by J. E. H. Peyton, Esq., F.G.S.

The following communications were read:—

1. "On Generic Characters in the Order Sauropterygia." By Prof. Owen, C.B., F.R.S., F.G.S., &c.

2. "On the Origin of Valley-Lakes, mainly with reference to the Lakes of the Northern Alps." By the Rev. A. Irving, B.A., B.Sc., F.G.S.

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January 10, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

T. W. Edgeworth David, Esq., St. Fagans, Cardiff, and Sydney, Australia; the Earl of Dysart, 29 Chesham Place, S.W.; John James Hamilton, Esq., Villa Clara, St. Mark's Road, Notting Hill, W.; Francis Alfred Lucas, Esq., 39 Gloucester Square, Hyde Park, W.; and Meaburn Staniland, Esq., Jun., Harrington Hall, Spilsby, were elected Fellows, and Dr. Otto Torell, F.C.G.S., of Stockholm, a Foreign Member of the Society.

The List of Donations to the Library was read.

Three specimens of Rocks from the Sierra Buttes, and a spherical stone from a Pot-hole, North Yuba river, Sierra Nevada mountains, California, were presented to the Museum by F. Tendron, Esq., F.G.S.

The following name of a Fellow of the Society was read out for the first time in conformity with the Bye-Laws (Sect. VI. B, Art. 6), in consequence of the non-payment of the arrears of his contribution :—J. T. Dawes, Esq.

The following communications were read :—

1. "On the Lower Eocene section between Reculvers and Herne Bay, and on some modifications in the classification of the Lower London Tertiaries." By J. S. Gardner, Esq., F.G.S.

2. "On Mr. Dunn's Notes on the Diamond-fields of South Africa, 1880." By Francis Oats, Esq., F.G.S.

The author referred to the hypothesis put forward in 1880 by Mr. Dunn (Quart. Journ. Geol. Soc. vol. xxxvii. p. 609), that the carbon for the production of the South-African diamonds was furnished by the black carbonaceous shales found throughout the district, and the conclusion drawn by him therefrom that therefore diamonds would not be found below the level of these shales. The author stated that the shales, so far as he knows, do not occur below 270 feet, whilst the ground is successfully worked for diamonds at a depth of 350 feet. He maintained that the carbonaceous shales have nothing to do with the origin of the diamonds, and stated that the "craters" containing the diamantiferous rock erupted quite different material at an earlier date; and he instanced the occurrence in the Kimberley mine of a mass of "dolerite" between the diamantiferous ground and the surrounding shales.

The following specimens were exhibited :—

Specimens of quartz with gold, from the Sierra Buttes Mine, California, exhibited by F. Tendron, Esq., F.G.S.

A *Perna* and other fossils from the lowest division of the Woolwich and Reading Bottom Bed, in the Croydon section of the Woodside and East Grinstead Railway, exhibited by H. M. Klaassen, Esq., F.G.S.

A specimen from the Oxford Clay, exhibited by T. J. George, Esq., F.G.S.; and

A series of fossils, exhibited by J. S. Gardner, Esq., F.G.S., in illustration of his paper.

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January 24, 1883.

J. GWYN JEFFREYS, LL.D., F.R.S., Vice-President, in the Chair.

Walter Raleigh Browne, Esq., M. Inst. C.E., 38 Belgrave Road, S.W.; Thomas Charles Maggs, Esq., Yeovil; Lieut.-Col. William Alexander Ross, R.A., Acton House, Acton, W.; and Cecil Carus Wilson, Esq., Mayland Vicarage, Maldon, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following name of a Fellow of the Society was read out for the second time in conformity with the Bye-Laws (Sec. VI. B, Art. 6), in consequence of the non-payment of the arrears of his contribution:—J. T. Dawes, Esq.

The following communications were read:—

1. "On *Streptelasma Roemeri*, sp. nov., from the Wenlock Shale." By Prof. P. Martin Duncan, M.B. (Lond.), F.R.S., V.P.G.S.

2. "On *Cyathophyllum Fletcheri*, Edw. & H., sp." By Prof. P. Martin Duncan, M.B. (Lond.), F.R.S., V.P.G.S.

3. "On the Fossil Madreporaria of the Great Oolite of the Counties of Gloucester and Oxford." By Robert F. Tomes, Esq., F.G.S.

Specimens of fossil corals were exhibited by Prof. P. M. Duncan, F.R.S., V.P.G.S., and R. F. Tomes, Esq., F.G.S., in illustration of their papers.

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February 7, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

G. E. D'Arcy Adams, Esq., M.D., 1 Clifton Gardens, W.; Prof. Ferdinand Moritz Krausé, School of Mines, Ballarat, Australia; and the Rev. Alfred William Rowe, M.A., Felstead School, Essex, were elected Fellows, and Dr. Karl A. Zittel, of Munich, a Foreign Correspondent of the Society.



The List of Donations to the Library was read.

The following communications were read:—

1. "On the Metamorphic and Overlying Rocks in parts of Ross and Inverness shires." By Henry Hicks, M.D., F.G.S. With Notes on the Microscopic structure of some of the Rocks, by Prof. T. G. Bonney, M.A., F.R.S., Sec.G.S.

2. "On the Lower Carboniferous Rocks in the Forest of Dean, as represented in typical sections at Drybrook." By E. Wethered, Esq., F.G.S., F.C.S.

Specimens were exhibited by Dr. Hicks and E. Wethered, Esq., in illustration of their papers.

*ANNUAL GENERAL MEETING,*

February 16, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

REPORT OF THE COUNCIL FOR 1882.

IN presenting their Report for the year 1882, the Council of the Geological Society regret that they are unable to announce to the Fellows any marked general improvement in the condition of the Society's affairs, as compared with that shown in their last year's Report. In one particular, indeed, there is, unfortunately, a falling off, the number of Fellows of the Society having suffered an actual, although very small, decrease. This continued depression is evidently due to the same causes that were indicated last year, and therefore, it is to be hoped, of a temporary nature; and it is some satisfaction to find that the Income of the Society during the past year showed an increase upon that of the year 1881.

The number of Fellows elected during the year is 45, of whom 36 paid their fees before the end of the year, making, with 7 previously elected Fellows who paid their fees in 1882, a total accession during the year of only 43 Fellows. Against this we have to set the loss by death of 27 Fellows, and by resignation of 13 Fellows, while 4 Fellows were removed from the list for non-payment of contributions, making a total loss of 44 Fellows. On the year, therefore, there is a loss of 1 Fellow. But of the 27 Fellows deceased, 5 were compounders, and 10 non-contributing Fellows, while 1 non-contributing Fellow became resident; and thus the number of contributing Fellows is actually increased by 9, being now 800.

The total number of Fellows and Foreign Members and Correspondents was 1443 at the end of the year 1881, and 1441 at the end of 1882.

At the end of the year 1881 there was one vacancy in the list of Foreign Members; and during 1882 intelligence was received of the death of 2 Foreign Members. Two of these vacancies in the list of Foreign Members were filled up during the year. The death of a Foreign Correspondent in 1882, and the filling-up of the above-mentioned vacancies in the list of Foreign Members produced three vacancies in the list of Foreign Correspondents, two of which were filled up during the year. Thus at the close of 1882 there was one

vacancy in each of the Foreign lists, both of which have since been filled.

The total Receipts on account of Income for the year 1882 were £2663 16s. 2*d.*, being £9 2s. 4*d.* less than the estimated Income for the year. The total Expenditure, on the other hand, amounted to £2644 19s. 5*d.*, or £118 3s. 7*d.* more than the estimated Expenditure of the year, the excess being chiefly incurred in connexion with the production of the Quarterly Journal.

At the desire of the President, who kindly bore half the expense of the evening, a *Conversazione* was held in the Society's Rooms on the 24th November last. The attendance was hardly so numerous as might have been expected; but in all other respects the entertainment was highly successful.

The Council have to announce that Mr. G. W. Ormerod has kindly prepared a Second Supplement to his valuable Classified Index to the publications of the Society, including the volumes of the Quarterly Journal published from 1876 to 1882 inclusive (Vols. XXXII. to XXXVIII.). The thanks of the Society are due to Mr. Ormerod for the labour and care he has devoted to the task of keeping this useful guide to the contents of the Society's Publications up to date. The manuscript of this Second Supplement has been furnished by Mr. Ormerod, and is now in the printer's hands. It will be of about the same size as the First Supplement (published in 1876), and will be issued to Fellows at the same price, namely one shilling.

The Council have to announce the completion of Vol. XXXVIII. and the commencement of Vol. XXXIX. of the Society's Quarterly Journal.

The Council have awarded the Wollaston Medal to W. T. Blanford, Esq., F.R.S., F.G.S., in recognition of services rendered by him to Geology in Abyssinia and Eastern Persia, and during his long-continued labours in connexion with the Geological Survey of India.

The Murchison Medal, with the sum of Ten Guineas from the proceeds of the Fund, has been awarded to Professor H. R. Göppert, F.M.G.S., in testimony of appreciation of his valuable researches in connexion with Palæozoic Botany, which have extended over a period of 50 years.

The Lyell Medal, with a sum of Twenty-five Pounds from the proceeds of the Fund, has been awarded to Dr. W. B. Carpenter, C.B., F.R.S., F.G.S., in recognition of the value of his investigations into the Microscopic Structure of Fossils, especially the Foraminifera, and of his labours in connexion with the exploration of the deeper parts of the Ocean.

The Bigsby Medal has been awarded to Henry Hicks, M.D., F.G.S., as a token of appreciation of the importance of his labours among the Oldest Fossiliferous and Archæan Rocks of the British Islands.

The balance of the proceeds of the Wollaston Donation Fund has been awarded to Professor John Milne, F.G.S., in recognition of the interest attaching to his valuable investigations into the Earthquake-phenomena of Japan, and to assist him in further seismic observations.

The balance of the proceeds of the Murchison Donation Fund has been awarded to John Young, Esq., F.G.S., Curator of the Hunterian Museum in the University of Glasgow, in recognition of his long-continued researches among the Polyzoa and other minute fossil organisms of the Carboniferous strata of the west of Scotland, and to assist him in further investigations of a like kind.

The balance of the proceeds of the Lyell Donation Fund has been awarded, in equal parts, to P. H. Carpenter, Esq., M.A., as a testimony to the importance of his investigations into the structure and relationships of the fossil Crinoidea, and to assist him in extending his researches to the order Blastoidea; and to M. Rigaux, of Boulogne, in recognition of the value of his investigations upon the fossils of the Devonian and Jurassic series of the Boulonnais, and to aid him in the further prosecution of his researches.

#### REPORT OF THE LIBRARY AND MUSEUM COMMITTEE.

##### *Library.*

Since the last Anniversary Meeting a great number of valuable additions have been made to the Library, both by donation and by purchase.

As Donations the Library has received about 107 volumes of separately published works and Survey Reports, and about 188 Pamphlets and separate impressions of Memoirs; also about 137 volumes and 102 detached parts of the publications of various Societies, and 16 volumes of independent Periodicals presented chiefly by their respective Editors, besides 22 volumes of Newspapers of various kinds. This will constitute a total addition to the Society's Library, by donation, of about 310 volumes and 188 pamphlets.

A considerable number of Maps, Plans, and Sections have been added to the Society's collections by presentation from various Geological Surveys, from the Ordnance Survey of Great Britain, and from the French Dépôt de la Marine. They amount all together to 270 sheets, and include 225 sheets from the Ordnance Survey, and 26 sheets from the Dépôt de la Marine; the Geological Surveys from which Maps have been received are those of Belgium, Finland, Saxony, Sweden, and Switzerland.

The Books and Maps just referred to have been received from 127 personal Donors, the Editors or Publishers of 15 Periodicals, and 140 Societies, Surveys, and other Public Bodies, making in all 283 Donors.

By Purchase, on the recommendation of the Standing Library Committee, the Library has received the addition of 50 volumes of Books, and of 44 parts (making about 8 volumes) of Periodicals,



besides 38 parts of various works published serially. Of the Geological Survey Map of France, 4 sheets and a sheet of sections have been obtained by purchase; and the Society has also purchased M. Leymerie's Geological Map of the Haute Garonne in 1 sheet, and a copy of the 'Carta Geologica d' Italia,' in 2 sheets.

The cost of Books, Periodicals, and Maps during the year 1882 was £72 12s. 7d., and of Binding £36 14s. 10d. There was also expended on the mounting of Maps a sum of £13 13s. 4d., and on mounting the new Library Catalogue on writing-paper, in two volumes, £1 16s. 8d. The total expenditure on account of the Library was £124 17s. 5d.

The Books in the Society's Library are generally in good condition; and the bindings of many of the older volumes have been repaired during the past year. The Library continues to be much consulted by the Fellows of the Society.

#### *Museum.*

The Collections in the Museum remain in much the same condition as at the date of the last Report of the Committee.

During the year 1882 several interesting Donations have been made to the Museum, including:—Rock-specimens from Costa Rica, presented by G. Attwood, Esq., F.G.S., and a specimen of *Oleandridium Beyrichii*, Schenk, from the Wealden, near Hastings, presented by J. E. H. Peyton, Esq., F.G.S., in illustration of communications read before the Society; a fine example of *Platax altissimus*, from Monte Bolca, presented by Lieut.-General Randolph; four specimens of building-stones in common use in Mexico, presented by F. Newman, Esq., F.G.S.; and a case of fossils, rocks, and minerals from the Department of Salto, Uruguay, presented by A. Mackinnon, Esq., F.G.S.

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COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE  
CLOSE OF THE YEARS 1881 AND 1882.

	Dec. 31, 1881.	Dec. 31, 1882.
Compounders .....	311	312
Contributing Fellows... ..	791	800
Non-contributing Fellows..	259	248
	<hr/> 1361	<hr/> 1360
Honorary Members .....	3	3
Foreign Members .....	39	39
Foreign Correspondents....	40	39
	<hr/> 1443	<hr/> 1441

*General Statement explanatory of the Alterations in the Number of  
Fellows, Honorary Members, &c. at the close of the years 1881 and  
1882.*

Number of Compounders, Contributing and Non-contributing Fellows, December 31, 1881 . . . .	}	1361
<i>Add</i> Fellows elected during former year and paid in 1882 . . . . .		
<i>Add</i> Fellows elected and paid in 1882 . . . . .	}	7
		36
		<hr/> 1404
<i>Deduct</i> Compounders deceased . . . . .	5	
Contributing Fellows deceased . . . . .	12	
Non-contributing Fellows deceased . . . .	10	
Contributing Fellows resigned . . . . .	13	
Contributing Fellows removed . . . . .	4	
	—	44
		<hr/> 1360
Number of Honorary Members, Foreign Members, and Foreign Correspondents, December 31, 1881 . . . . .	}	82
<i>Deduct</i> Foreign Members deceased . . . . .		
Foreign Correspondent deceased . . . .	1	
Foreign Correspondents elected }	}	2
Foreign Members . . . . .		
	—	5
		<hr/> 77
<i>Add</i> Foreign Members elected . . . . .	2	
Foreign Correspondents elected . . . . .	2	
	—	4
	—	81
		<hr/> 1441

## DECEASED FELLOWS.

*Compounders (5).*

Darwin, C. R., Esq.	Stow, G. W., Esq.
Parish, Sir Woodbine.	White, J., Esq.
Perry, Sir T. Erskine.	

*Resident and other Contributing Fellows (12).*

Adams, Prof. A. Leith.	Moggridge, M., Esq.
Brown, R., Esq.	Molyneux, W., Esq.
Davies, Rev. E.	Napier, C. G., Esq.
Francis, H., Esq.	Norman, G. W., Esq.
Grimshaw, W. J., Esq.	Sharp, S., Esq.
Mitchell, R., Esq.	Tawney, E. B., Esq.

*Non-contributing Fellows (10).*

Blanshard, H., Esq.	Moffat, Dr. T.
Calvert, J., Esq.	Noyes, T. H., Esq.
Falconer, T., Esq.	Thomson, Sir Wyville.
Hore, Rev. W. S.	Ward, Rev. J.
MacLauchlan, H., Esq.	Wood, Rev. H. H.

*Foreign Members (2).*

Desor, Prof. E.	Rogers, Prof. W. B.
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*Foreign Correspondent.*

Kobell, Prof. F. Ritter von.

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*Fellows Resigned (13).*

Brooke, Sir V. A., Bart.	Marshall, J., Esq.
Cherry, J. L., Esq.	Pooley, E., Esq.
Etheridge, R., jun., Esq.	Richardson, Dr. C. T.
Griffiths, E. H., Esq.	Shrubsole, W. H., Esq.
Guppy, R. J. L., Esq.	Slatter, G. W., Esq.
Johnston, Dr. W.	Vyse, G. W., Esq.
Leach, Rev. C.	

*Fellows Removed (4).*

Dyke, E. G., Esq.	Maury, M. F., jun., Esq.
Lucas, Joseph, Esq.	Williamson, E., Esq.

*The following Personages were elected from the List of Foreign Correspondents to fill the vacancies in the List of Foreign Members during the year 1882.*

Professor Sven Lovén of Stockholm.  
Professor Ludwig Rüttimeyer of Basle.

*The following Personages were elected Foreign Correspondents during the year 1882.*

Professor Louis Lartet of Toulouse.  
Professor Alphonse Milne-Edwards of Paris.

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After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and distributed among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Professor N. S. Maskelyne and Professor J. Morris, retiring from the office of Vice-President.

That the thanks of the Society be given to J. C. Hawkshaw, Esq., Sir J. Lubbock, Bart., Professor N. S. Maskelyne, Professor J. Morris, and Dr. H. Woodward, retiring from the Council.

After the Balloting-glasses had been duly closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—



## OFFICERS.

*PRESIDENT.*

J. W. Hulke, Esq., F.R.S.

*VICE-PRESIDENTS.*

Prof. P. M. Duncan, M.B., F.R.S.

R. Etheridge, Esq., F.R.S.

J. Gwyn Jeffreys, LL.D., F.R.S.

Prof. J. Prestwich, M.A., F.R.S.

*SECRETARIES.*

Prof. T. G. Bonney, M.A., F.R.S.

Prof. J. W. Judd, F.R.S.

*FOREIGN SECRETARY.*

W. W. Smyth, Esq., M.A., F.R.S.

*TREASURER.*

Prof. T. Wiltshire, M.A., F.L.S.

## COUNCIL.

H. Bauerman, Esq.

W. T. Blanford, Esq., F.R.S.

Prof. T. G. Bonney, M.A., F.R.S.

W. Carruthers, Esq., F.R.S.

Prof. P. M. Duncan, M.B., F.R.S.

R. Etheridge, Esq., F.R.S.

J. Evans, D.C.L., LL.D., F.R.S.

A. Geikie, LL.D., F.R.S.

Rev. Edwin Hill, M.A.

G. J. Hinde, Ph.D.

Prof. T. McKenny Hughes, M.A.

J. W. Hulke, Esq., F.R.S.

J. Gwyn Jeffreys, LL.D., F.R.S.

Prof. T. Rupert Jones, F.R.S.

Prof. J. W. Judd, F.R.S.

S. R. Pattison, Esq.

J. A. Phillips, Esq., F.R.S.

Prof. J. Prestwich, M.A., F.R.S.

F. W. Rudler, Esq.

Prof. H. G. Seeley, F.R.S.

Warington W. Smyth, Esq., M.A.,  
F.R.S.

W. Topley, Esq.

Prof. T. Wiltshire, M.A., F.L.S.

# LIST OF THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1882.

Date of  
Election.

- 1827. Dr. H. von Dechen, *Bonn*.
- 1844. William Burton Rogers, Esq., *Boston, U. S. (Deceased.)*
- 1848. James Hall, Esq., *Albany, State of New York*.
- 1850. Professor Bernhard Studer, *Berne*.
- 1851. Professor James D. Dana, *New Haven, Connecticut*.
- 1853. Count Alexander von Keyserling, *Rayküll, Russia*.
- 1853. Professor L. G. de Koninck, *Liège*.
- 1854. M. Joachim Barrande, *Prague*.
- 1856. Professor Robert Bunsen, For. Mem. R.S., *Heidelberg*.
- 1857. Professor H. R. Göppert, *Breslau*.
- 1857. Professor H. B. Geinitz, *Dresden*.
- 1857. Dr. Hermann Abich, *Vienna*.
- 1859. Dr. Ferdinand Römer, *Breslau*.
- 1860. Dr. H. Milne-Edwards, For. Mem. R.S., *Paris*.
- 1862. Professor Pierre Merian, *Basle*.
- 1864. M. Jules Desnoyers, *Paris*.
- 1866. Dr. Joseph Leidy, *Philadelphia*.
- 1867. Professor A. Daubrée, For. Mem. R.S., *Paris*.
- 1870. Professor Oswald Heer, *Zurich*.
- 1871. Dr. Sven Nilsson, *Lund*.
- 1871. Dr. Franz Ritter von Hauer, *Vienna*.
- 1874. Professor Alphonse Favre, *Geneva*.
- 1874. Professor E. Hébert, *Paris*.
- 1874. Professor Édouard Desor, *Neuchâtel. (Deceased.)*
- 1874. Professor Albert Gaudry, *Paris*.
- 1875. Professor Fridolin Sandberger, *Würzburg*.
- 1875. Professor Theodor Kjerulf, *Christiania*.
- 1875. Professor F. August Quenstedt, *Tübingen*.
- 1876. Professor E. Beyrich, *Berlin*.
- 1877. Dr. Carl Wilhelm Gümbel, *Munich*.
- 1877. Dr. Eduard Suess, *Vienna*.
- 1879. Dr. F. V. Hayden, *Washington*.
- 1879. Major-General N. von Kokscharow, *St. Petersburg*.
- 1879. M. Jules Marcou, *Cambridge, U. S.*
- 1879. Dr. J. J. S. Steenstrup, For. Mem. R.S., *Copenhagen*.
- 1880. Professor Gustave Dewalque, *Liège*.
- 1880. Baron Adolf Erik Nordenskiöld, *Stockholm*.
- 1880. Professor Ferdinand Zirkel, *Leipzig*.
- 1881. Il Commendatore Quintino Sella, *Rome*.
- 1882. Professor Sven Lovén, *Stockholm*.
- 1882. Professor Ludwig Rüttimeyer, *Basle*.

LIST OF  
THE FOREIGN CORRESPONDENTS  
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1882.

Date of  
Election.

- 1863. Dr. G. F. Jäger, *Stuttgart*.
- 1863. Count A. G. Marschall, *Vienna*.
- 1863. Professor G. Meneghini, *Pisa*.
- 1863. Professor Giuseppe Ponzi, *Rome*.
- 1863. Dr. F. Senft, *Eisenach*.
- 1864. Dr. Charles Martins, *Montpellier*.
- 1866. Professor J. P. Lesley, *Philadelphia*.
- 1866. Professor Victor Raulin, *Bordeaux*.
- 1866. Baron Achille de Zigno, *Padua*.
- 1870. Professor Joseph Szabó, *Pesth*.
- 1870. Professor Otto Torell, *Lund*.
- 1871. M. Henri Coquand, *Marseilles*.
- 1871. Professor Giovanni Capellini, *Bologna*.
- 1872. Herr Dionys Stur, *Vienna*.
- 1872. Professor J. D. Whitney, *Cambridge, U. S.*
- 1874. Professor Iginò Cocchi, *Florence*.
- 1874. M. Gustave H. Cotteau, *Auxerre*.
- 1874. Professor G. Seguenza, *Messina*.
- 1874. Dr. J. S. Newberry, *New York*.
- 1874. Dr. T. C. Winkler, *Haarlem*.
- 1875. Professor Gustav Tschermak, *Vienna*.
- 1876. Professor Jules Gosselet, *Lille*.
- 1877. Professor George J. Brush, *New Haven*.
- 1877. Professor A. L. O. Des Cloizeaux, *For. Mem. R.S., Paris*.
- 1877. Professor E. Renevier, *Lausanne*.
- 1877. Count Gaston de Saporta, *Aix-en-Provence*.
- 1879. Professor Pierre J. van Beneden, *For. Mem. R.S., Louvain*.
- 1879. M. Édouard Dupont, *Brussels*.
- 1879. Professor Guglielmo Guiscardi, *Naples*.
- 1879. Professor Franz Ritter von Kobell, *Munich*. (Deceased.)
- 1879. Professor Gerhard Vom Rath, *Bonn*.
- 1879. Dr. Émile Sauvage, *Paris*.
- 1880. Professor Luigi Bellardi, *Turin*.
- 1880. Dr. Ferdinand von Hochstetter, *Vienna*.
- 1880. Professor Leo Lesquereux, *Columbus*.
- 1880. Dr. Melchior Neumayr, *Vienna*.
- 1880. M. Alphonse Renard, *Brussels*.
- 1881. Professor E. D. Cope, *Philadelphia*.
- 1882. Professor Louis Lartet, *Toulouse*.
- 1882. Professor Alphonse Milne-Edwards, *Paris*.

# AWARDS OF THE WOLLASTON MEDAL

## UNDER THE CONDITIONS OF THE "DONATION FUND"

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., &amp;c.

"To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,"—"such individual not being a Member of the Council."

- |                                     |                                   |
|-------------------------------------|-----------------------------------|
| 1831. Mr. William Smith.            | 1858. } Herr Hermann von Meyer.   |
| 1835. Dr. G. A. Mantell.            | } Mr. James Hall.                 |
| 1836. M. L. Agassiz.                | 1859. Mr. Charles Darwin.         |
| 1837. } Capt. T. P. Cautley.        | 1860. Mr. Searles V. Wood.        |
| } Dr. H. Falconer.                  | 1861. Professor Dr. H. G. Bronn.  |
| 1838. Professor R. Owen.            | 1862. Mr. R. A. C. Godwin-Austen. |
| 1839. Professor C. G. Ehrenberg.    | 1863. Professor Gustav Bischof.   |
| 1840. Professor A. H. Dumont.       | 1864. Sir R. I. Murchison.        |
| 1841. M. Adolphe T. Brongniart.     | 1865. Dr. Thomas Davidson.        |
| 1842. Baron L. von Buch.            | 1866. Sir Charles Lyell.          |
| 1843. } M. Elie de Beaumont.        | 1867. Mr. G. Poulett Scrope.      |
| } M. P. A. Dafrénoy.                | 1868. Professor Carl F. Naumann.  |
| 1844. Rev. W. D. Conybeare.         | 1869. Dr. H. C. Sorby.            |
| 1845. Professor John Phillips.      | 1870. Professor G. P. Deshayes.   |
| 1846. Mr. William Lonsdale.         | 1871. Sir A. C. Ramsay.           |
| 1847. Dr. Ami Boué.                 | 1872. Professor J. D. Dana.       |
| 1848. Rev. Dr. W. Buckland.         | 1873. Sir P. de M. Grey-Egerton.  |
| 1849. Professor Joseph Prestwich.   | 1874. Professor Oswald Heer.      |
| 1850. Mr. William Hopkins.          | 1875. Professor L. G. de Koninck. |
| 1851. Rev. Prof. A. Sedgwick.       | 1876. Professor T. H. Huxley.     |
| 1852. Dr. W. H. Fitton.             | 1877. Mr. Robert Mallet.          |
| 1853. } M. le Vicomte A. d'Archiac. | 1878. Dr. Thomas Wright.          |
| } M. E. de Verneuil.                | 1879. Professor Bernhard Studer.  |
| 1854. Sir Richard Griffith.         | 1880. Professor Auguste Daubrée.  |
| 1855. Sir H. T. De la Beche.        | 1881. Professor P. Martin Duncan. |
| 1856. Sir W. E. Logan.              | 1882. Dr. Franz Ritter von Hauer. |
| 1857. M. Joachim Barrande.          | 1883. Mr. W. T. Blanford.         |



## AWARDS

OF THE

## BALANCE OF THE PROCEEDS OF THE WOLLASTON

## "DONATION-FUND."

1831. Mr. William Smith.	1859. Mr. Charles Peach.
1833. Mr. William Lonsdale.	1860. } Professor T. Rupert Jones.
1834. M. Louis Agassiz.	1860. } Mr. W. K. Parker.
1835. Dr. G. A. Mantell.	1861. Professor A. Daubrée.
1836. Professor G. P. Deshayes.	1862. Professor Oswald Heer.
1838. Professor Richard Owen.	1863. Professor Ferdinand Senft.
1839. Professor C. G. Ehrenberg.	1864. Professor G. P. Deshayes.
1840. Mr. J. De Carle Sowerby.	1865. Mr. J. W. Salter.
1841. Professor Edward Forbes.	1866. Dr. Henry Woodward.
1842. Professor John Morris.	1867. Mr. W. H. Bailly.
1843. Professor John Morris.	1868. M. J. Bosquet.
1844. Mr. William Lonsdale.	1869. Mr. W. Carruthers.
1845. Mr. Geddes Bain.	1870. M. Marie Rouault.
1846. Mr. William Lonsdale.	1871. Mr. R. Etheridge.
1847. M. Alcide d'Orbigny.	1872. Mr. James Croll.
1848. } Cape-of-Good-Hope Fossils.	1873. Professor J. W. Judd.
1848. } M. Alcide d'Orbigny.	1874. Dr. Henri Nyst.
1849. Mr. William Lonsdale.	1875. Mr. L. C. Miall.
1850. Professor John Morris.	1876. Professor Giuseppe Seguenza.
1851. M. Joachim Barrande.	1877. Mr. R. Etheridge, Jun.
1852. Professor John Morris.	1878. Mr. W. J. Sollas.
1853. Professor L. G. de Koninck.	1879. Mr. S. Allport.
1854. Mr. S. P. Woodward.	1880. Mr. Thomas Davies.
1855. Drs. G. and F. Sandberger.	1881. Dr. R. H. Traquair.
1856. Professor G. P. Deshayes.	1882. Dr. G. J. Hinde.
1857. Mr. S. P. Woodward.	1883. Professor J. Milne.
1858. Mr. James Hall.	

## AWARDS OF THE MURCHISON MEDAL

AND OF THE

## PROCEEDS OF "THE MURCHISON GEOLOGICAL FUND,"

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, BART., F.R.S., F.G.S.

"To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing geological science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any inquiries bearing upon the science of geology, or in rewarding any

such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of geological science."

1873. Mr. William Davies. <i>Medal.</i>	1878. Mr. C. Lapworth.
1873. Professor Oswald Heer.	1879. Professor F. M'Coy. <i>Medal.</i>
1874. Dr. J. J. Bigsby. <i>Medal.</i>	1879. Mr. J. W. Kirkby.
1874. Mr. Alfred Bell.	1880. Mr. R. Etheridge. <i>Medal.</i>
1874. Professor Ralph Tate.	1881. Professor A. Geikie. <i>Medal.</i>
1875. Mr. W. J. Henwood. <i>Medal.</i>	1881. Mr. F. Rutley.
1875. Prof. H. G. Seeley.	1882. Professor J. Gosselet. <i>Medal.</i>
1876. Mr. A. R. C. Selwyn. <i>Medal.</i>	1882. Professor T. Rupert Jones.
1876. Mr. James Croll.	1883. Professor H. R. Göppert. <i>Medal.</i>
1877. Rev. W. B. Clarke. <i>Medal.</i>	1883. Mr. John Young.
1877. Rev. J. F. Blake.	
1878. Dr. H. B. Geinitz. <i>Medal.</i>	

## AWARDS OF THE LYELL MEDAL

AND OF THE

PROCEEDS OF THE "LYELL GEOLOGICAL FUND,"

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE  
SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal "to be given annually" (or from time to time) "as a mark of honorary distinction as an expression on the part of the governing body of the Society that the Medallist has deserved well of the Science,"—"not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced."

1876. Professor John Morris. <i>Medal.</i>	1880. Professor F. Quenstedt.
1877. Dr. James Hector. <i>Medal.</i>	1881. Principal J. W. Dawson. <i>Medal.</i>
1877. Mr. W. Pengelly.	1881. Dr. Anton Fritsch.
1878. Mr. G. Busk. <i>Medal.</i>	1881. Mr. G. R. Vine.
1878. Dr. W. Waagen.	1882. Dr. J. Lycett. <i>Medal.</i>
1879. Professor Edmond Hébert. <i>Medal.</i>	1882. Rev. Norman Glass.
1879. Professor H. A. Nicholson.	1882. Professor C. Lapworth.
1879. Dr. Henry Woodward.	1883. Dr. W. B. Carpenter. <i>Medal.</i>
1880. Mr. John Evans. <i>Medal.</i>	1883. Mr. P. H. Carpenter.
	1883. M. E. Rigau.

## AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially "as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much."

1877. Professor O. C. Marsh.

1881. Dr. C. Barrois.

1879. Professor E. D. Cope.

1883. Dr. Henry Hicks.

## AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

"The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science."

1880. Purchase of microscope.

1882. Baron C. von Ettingshausen.

1881. Purchase of microscope lamps.

ESTIMATES *for*

## INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Due for Subscriptions for Quarterly Journal ..	3	4	0			
Due for Arrears of Annual Contributions .....	190	0	0			
Due for Arrears of Admission-fees .....	50	8	0			
	<hr/>			243	12	0
Estimated Ordinary Income for 1883 :—						
Annual Contributions from Resident Fellows, and Non-residents of 1859 to 1861 .....	1420	0	0			
Admission-fees .....	226	16	0			
Compositions .....	199	10	0			
Annual Contributions in advance .....	21	0	0			
Dividends on Consols and Reduced 3 per Cents .....	233	0	11			
Advertisements in Quarterly Journal.....	8	10	0			
Sale of Transactions, Library-catalogue, Ormerod's Index, Hochstetter's New Zealand, and List of Fellows .....	10	0	0			
Sale of Quarterly Journal, including Longman's account .....	220	0	0			
Sale of Geological Map, including Stanford's account .....	25	0	0			
	<hr/>			255	0	0

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£2607 8 11

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THOMAS WILTSHIRE, TREAS.

7 Feb. 1883.



*the Year 1883.*

## EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes and Insurance .....	36	3	9			
Gas .....	25	0	0			
Fuel .....	35	0	0			
Furniture .....	15	0	0			
House-repairs and Maintenance.....	20	0	0			
Annual Cleaning .....	20	0	0			
Washing and sundry small Expenses .....	35	0	0			
Tea at Meetings .....	16	0	0			
				202	3	9
Salaries and Wages:						
Assistant Secretary .....	350	0	0			
Clerk .....	160	0	0			
Assistant in Library and Museum .....	110	0	0			
House Steward .....	105	0	0			
Housemaid .....	40	0	0			
Errand Boy .....	41	12	0			
Charwoman and Occasional Assistance.....	30	0	0			
Attendants at Meetings .....	8	0	0			
Accountants .....	10	10	0			
				855	2	0
Official Expenditure:						
Stationery .....	25	0	0			
Miscellaneous Printing .....	20	0	0			
Postages and other expenses .....	62	0	0			
				107	0	0
Library .....				125	0	0
Publications:						
Geological Map .....	16	0	0			
Quarterly Journal .....	1000	0	0			
"    "    Commission, Postage, and Addressing .....	100	0	0			
List of Fellows .....	35	0	0			
Abstracts, including Postage .....	105	0	0			
Ormerod's Index .....	33	10	0			
				1289	10	0
Balance in favour of the Society.....				28	13	2
				£2607	8	11

*Income and Expenditure during the*

## RECEIPTS.

	£	s.	d.	£	s.	d.
Balance in Bankers' hands, 1 January 1882.	66	3	10			
Balance in Clerk's hands, 1 January 1882.	14	16	7			
	<hr/>			81	0	5
Compositions .....				199	10	0
Arrears of Admission-fees .....	44	2	0			
Admission-fees, 1882 .....	226	16	0			
	<hr/>			270	18	0
Arrears of Annual Contributions .....				201	19	6
Annual Contributions for 1882, viz.:—						
Resident Fellows .....	1402	5	6			
Non-Resident Fellows ...	20	9	6			
	<hr/>			1422	15	0
Annual Contributions in advance .....				27	6	0
Dividends on Consols .....	202	14	0			
,, Reduced 3 per Cents .....	30	6	11			
	<hr/>			233	0	11
Taylor & Francis: Advertisements in Journal, Vol. 37..				9	9	0
Publications:						
Sale of Journal, Vols. 1-37 .....	166	3	0			
,, Vol. 38* .....	91	13	7			
Sale of Library Catalogue .....	7	13	0			
Sale of Geological Map .....	31	12	8			
Sale of Ormerod's Index .....	1	8	6			
Sale of Hochstetter's New Zealand .....	0	6	0			
Sale of List of Fellows .....	0	1	0			
	<hr/>			298	17	9
*Due from Messrs. Longman, in addition to the above, on Journal, Vol. 38, &c.....	63	12	4			
Due from Stanford on account of Geological Map	10	15	0			
	<hr/>			74	7	4
	<hr/>					

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£2744 16 7

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We have compared this statement  
with the Books and Accounts presented  
to us, and find them to agree.

(Signed) H. BAUERMAN, }  
          W. H. HUDLESTON, } *Auditors.*

7 Feb. 1883.

*Year ending 31 December, 1882.*

## EXPENDITURE.

House Expenditure:	£	s.	d.	£	s.	d.
Taxes .....	18	5	10			
Fire-insurance .....	12	0	0			
Gas .....	22	1	9			
Fuel.....	31	17	6			
Furniture .....	6	8	3			
House-repairs and Maintenance .....	27	2	2			
Annual Cleaning .....	19	14	0			
Washing and sundry small Expenses .....	36	2	9			
Tea at Meetings.....	16	0	0			
				189	12	3
Salaries and Wages :						
Assistant Secretary .....	350	0	0			
Clerk .....	160	0	0			
Assistant in Library and Museum .....	110	0	0			
House Steward .....	105	0	0			
Housemaid .....	40	0	0			
Errand Boy .....	40	16	0			
Charwoman and Occasional Assistance .....	27	15	0			
Attendants at Meetings.....	8	0	0			
Accountants .....	10	10	0			
				852	1	0
Official Expenditure :						
Stationery .....	24	4	1			
Miscellaneous Printing.....	19	3	6			
Diagrams at Meetings .....	2	3	6			
Postages and other Expenses .....	58	19	5			
				104	10	6
Library .....				124	17	5
Soirée .....	67	3	11			
„ less amount paid by the President..	33	11	11			
				33	12	0
Publications :						
Geological Map .....	7	0	3			
Journal, Vols. 1-37.....	14	10	6			
„ Vol. 38 .....	1083	18	11			
„ „ Commission,						
Postage, and Addressing. 96 14 2						
	1180	13	1			
List of Fellows.....	33	13	0			
Abstracts, including Postage .....	104	9	5			
				1340	6	3
Balance in Bankers' hands, 31 Dec. 1882..	98	11	7			
Balance in Clerk's hands, 31 Dec. 1882 ..	1	5	7			
				99	17	2
				<u>£2744</u>	<u>16</u>	<u>7</u>

"WOLLASTON DONATION FUND." TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
Balance at Bankers', 1 January 1882 .....	31 15 7	Cost of striking Gold Medal awarded to Dr. Franz Ritter von Hauer .....	10 10 0
Dividends on the Fund invested in Reduced 3 per Cents. .	31 14 10	Award to Dr. G. J. Hinde .....	18 2 7
		Part cost of New Dies (second instalment) .....	3 3 0
		Balance at Bankers', 31 December 1882 .....	31 14 10
	<u>£63 10 5</u>		<u>£63 10 5</u>

"MURCHISON GEOLOGICAL FUND." TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
Balance at Bankers', 1 January 1882 .....	19 10 10	Award to Prof. J. Gosselet, with Medal .....	10 10 0
Dividends on the Fund invested in London and North-Western Railway 4 per cent. Debenture Stock .....	39 3 4	Prof. T. Rupert Jones .....	28 12 6
		Balance at Bankers', 31 December 1882 .....	19 11 8
	<u>£58 14 2</u>		<u>£58 14 2</u>



"LYELL GEOLOGICAL FUND." TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
Balance at Bankers', 1 January 1882 .....	51 12 0	Award to Dr. J. Lyckett, with Medal .....	25 0 0
Dividends on the Fund invested in Metropolitan 3½ per cent. Stock .....	68 13 7	"    Rev. Norman Glass .....	21 18 3
		"    Prof. C. Lapworth .....	21 18 3
		Balance at Bankers', 31 December 1882 .....	51 9 1
	<u>£120 5 7</u>		<u>£120 5 7</u>

"BARLOW-JAMESON FUND." TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
Balance at Bankers', 1 January 1882 .....	32 16 10	Award to Baron C. von Ettingshausen .....	25 0 0
Dividends on the Fund invested in Consols .....	14 13 8	Balance at Bankers', 31 December 1882 .....	22 10 6
	<u>£47 10 6</u>		<u>£47 10 6</u>

"BIGSBY FUND." TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
Balance at Bankers', 1 January 1882 .....	6 2 9	Balance at Bankers', 31 December 1882 .....	12 5 4
Dividends on the Fund invested in New 3 per Cents .....	6 2 7		
	<u>£12 5 4</u>		<u>£12 5 4</u>

## VALUATION OF THE SOCIETY'S PROPERTY 31 December, 1882.

PROPERTY.		DEBTS.	
	£ s. d.		£ s. d.
Due from Longman & Co., on account of Journal, vol. xxxviii. &c.....	63 12 4	Balance in favour of the Society.....	8433 16 4
Due from Stanford on account of Map .....	10 15 0		
Due from Subscribers to Journal (considered good)....	3 4 0		
Balance in Bankers' hands, 31 Dec. 1882 .....	98 11 7		
Balance in Clerk's hands, 31 Dec. 1882 .....	1 5 7		
Funded Property:—	£ s. d.		
Consols, at 101 .....	6900 7 2		
Reduced 3 per Cents. at 101....	1036 5 5		
Arrears of Admission-fees (considered good).....	50 8 0		
Arrears of Annual Contributions (considered good)....	190 0 0		
	<u>£8433 16 4</u>		<u>£8433 16 4</u>

[N.B. The above does not include the value of the Collections, Library, Furniture, and stock of unsold Publications.]

THOMAS WILTSHIRE, *Treas.*

7 Feb. 1883.

## AWARD OF THE WOLLASTON MEDAL.

In presenting the Wollaston Gold Medal to Mr. W. T. BLANFORD, F.R.S., F.G.S., the President addressed him as follows :—

Mr. BLANFORD,—

The Council has awarded you its highest distinction, the Wollaston Medal, in recognition of your services to geology in Abyssinia, in Persia, and on the Geological Survey of the Indian Empire. They are so well and so generally known that it is not necessary for me to enlarge upon them here. Your writings, which treat of a not inconsiderable portion of the Eastern Hemisphere, comprise, in addition to geology, much information respecting the zoology and the climates of the countries in which you served. Stamped with thoroughness and comprehensiveness, they constitute important additions to our knowledge of those regions. In conferring upon you this distinction, the Council of the Geological Society desires to mark its sense of their great value.

Mr. BLANFORD, in reply, said :—

Mr. PRESIDENT,—

I find it difficult to express adequately my sense of the honour that the Geological Society has conferred upon me by the award of the Wollaston Medal, an honour enhanced by the flattering expressions which you, Sir, as President of the Society, have added to the gift. I believe that my own geological labours do not entitle me to this distinction, and that, for this award, I am indebted fully as much to the work of my colleagues on the Geological Survey of India as to my own, that in receiving the Medal I appear as their representative, and that I owe that fortunate position at least as much to a series of accidents as to my own merits, partly to my having been selected for work of wider interest, though not of greater importance, than that executed by my comrades, and partly to my having resisted for a longer period than some others the injurious effects of a tropical climate.

My own career in India is at an end ; but the twenty-seven years that have elapsed since I first landed in that country have witnessed the gradual accumulation of observations sufficient not merely to throw much light upon the geological structure and history of India itself, but occasionally to reflect a few rays on obscure spots in the geology of other regions. That the results of our labours have been considered worthy of so honourable an award by the Geological Society will, I am sure, prove most gratifying to my colleagues who

are still engaged in working out the geology of India, whilst to myself the Medal is an unexpected recompense for many years of laborious exploration.

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#### AWARD OF THE WOLLASTON DONATION FUND.

The PRESIDENT then handed the balance of the proceeds of the Wollaston Donation Fund to Prof. J. W. JUDD, F.R.S., Sec. G.S., for transmission to Prof. JOHN MILNE, F.G.S., of Tokio, Japan, and addressed him as follows:—

Prof. JUDD,—

The Council, in bestowing upon Mr. Milne the balance of the proceeds of the Wollaston Fund, wishes to mark its appreciation of the importance of his investigations into the phenomena of earthquakes, to which he has devoted so much time and attention during his residence in Japan.

In handing to you this cheque for transmission to him, I would ask you to convey to him the hopes of the Council that this award may assist him in continuing those inquiries in Seismology which he has proved himself so well able to undertake.

Professor JUDD, in reply, said:—

Mr. PRESIDENT,—

I feel sure that the pleasure with which my friend Prof. Milne will hear in his distant home of this award of the Council of this Society will be enhanced when he learns the kind and appreciative terms in which you have spoken of his work. When Mr. Milne left England last year, it was with the intention of visiting the several Italian observatories in which investigations on those minute earthquakes which are now attracting so much attention from geologists, are carried on. In Japan Prof. Milne hopes to have ample opportunities for applying these new modes of investigation; and I have no doubt that the award from the Wollaston Fund which has been made to him this day will be of material assistance to him in carrying on these important observations.

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#### AWARD OF THE MURCHISON MEDAL.

In handing the Murchison Medal to Mr. WARINGTON W. SMYTH, M.A., F.R.S., F.G.S., for transmission to Prof. HEINRICH ROBERT GÖPPERT, F.M.G.S., of Breslau, the PRESIDENT said:—



MR. WARINGTON SMYTH,—

The Council of the Geological Society has awarded one of its high distinctions, the Murchison Medal and a part of the proceeds of the Murchison Fund, to Prof. H. R. Göppert of Breslau, one of our Foreign Members, in recognition of his labours in fossil botany.

The very large number of papers, 245, recorded in the Scientific List of the Royal Society under Prof. Göppert's name, testifies to the zeal and success with which he has cultivated this branch of biology during half a century. In asking you to transmit to him this Medal, I would desire you to express to him the high estimation in which this Society holds his work.

MR. WARINGTON SMYTH, in reply, said :—

I have been requested by Prof. Göppert to convey to the Society his hearty thanks for the honour done him by the award of the Medal founded by his lamented friend and correspondent Sir R. Murchison. The announcement came at an opportune time, as serving in some degree to raise his spirits when suffering from a domestic bereavement. It happens also to have been coincident with the completion of the great work on his favourite subject of amber and its organic remains, first brought before this Society by our Medallist in 1845. And when I remind our younger Fellows that Göppert commenced writing on scientific subjects as far back as 1828, and that the number of his works and papers amounts in the Royal Society's Catalogue to 245, they will be apt to wonder that he was not years ago selected as the recipient of the highest honour the Society could bestow.

Regretting deeply the circumstances which prevent Dr. Göppert from being present on this occasion, I have great pleasure in receiving for him a mark of honour so well deserved by the veteran geologist, whose name stands in so prominent a position in the special branch of palæophytology.

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#### AWARD OF THE MURCHISON GEOLOGICAL FUND.

The PRESIDENT then handed to Prof. MORRIS, M.A., F.G.S., for transmission to Mr. JOHN YOUNG, F.G.S., the balance of the proceeds of the Murchison Geological Fund, and said :—

Professor MORRIS,—

The Council of the Geological Society in awarding to Mr. John Young, of the Hunterian Museum, Glasgow, the balance of the proceeds of the Murchison Donation Fund, wishes to mark its appre-

ciation of the value of his long-continued researches on the fossil Polyzoa, especially those of the western part of Scotland, and of his investigations into the structure of the shells of the Carboniferous Brachiopoda. In his absence, I have much pleasure in placing the amount in your hands for transmission to him.

Professor MORRIS, in reply, said :—

Mr. PRESIDENT,—

I have much pleasure in receiving the balance of the Murchison Fund for Mr. J. Young, who regrets his inability to attend, and has sent me the following letter to read to the Society :—

“ Hunterian Museum,  
“ University of Glasgow.  
“ Feb. 7th, 1883.

“ Dear Sir,—

“ Will you kindly convey to the President and Council of the Geological Society the gratification I feel at the honour they have conferred upon me by associating my name with those of the former recipients of the Murchison Geological Fund, and at the same time express my regret that circumstances prevent my being present at the Meeting of the Society to receive the award in person from the hands of the President.

“ I appreciate the honour all the more as having been altogether unexpected by me. It has been my greatest pleasure during my life to employ my leisure time as an humble investigator of the Carboniferous strata and fossils of the West of Scotland; but I never imagined that my work would merit the distinction which the Council of the Society have bestowed upon it.

“ My work among the Scottish Carboniferous fossils has led me to collect and study carefully under the microscope, not only the Microzoa but also the shell-structure of many of the larger organisms found in the strata; and that I have been fortunate in discovering some new forms, and also in finding some new points of structure in others already known and described, I attribute chiefly to the methods of research which I employed, and to the fact that the organisms found in our strata are often better preserved than is usual elsewhere.

“ It has been for me sufficient reward to have been able to assist, in however small a degree, several eminent palæontologists in their researches among some of the fossil groups, such as the Brachiopoda, Foraminifera, and Entomostraca, by sending them specimens from our western Scottish Coalfield, many of which have been figured and described. But the honour which the Society has now conferred upon me will, I trust, encourage me to further research among the Scottish Carboniferous fossils, in which, especially among the Polyzoa

and their allies, much still remains to be discovered. By so doing, I hope to fulfil in some measure the object which the illustrious geologist had in view when he instituted this fund.

“I remain, dear Sir,  
Yours faithfully,  
JOHN YOUNG.”

I may state in conclusion, that, in addition to the assistance rendered to other palæontologists to which Mr. Young so modestly alludes, he has within the period of the last twenty years published nearly 50 papers, the results of his researches during that time.

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#### AWARD OF THE LYELL MEDAL.

The PRESIDENT next presented the Lyell Medal to Dr. W. B. CARPENTER, C.B., F.R.S., F.G.S., and addressed him in the following words:—

Dr. CARPENTER,—

The Council of the Geological Society has awarded to you the Lyell Medal with (in compliance with the terms of the bequest) a portion of the proceeds of the Lyell Fund, in recognition of the great value of your investigations into the minute structure of invertebrate fossils and of your deep-sea researches. Your contributions “On the Structure and Affinities of the *Eozoon canadense*,” “On the Microscopic Structure of *Nummulina*, *Orbitolites*, and *Orbitoides*,” published in our Journal, your numerous papers on the intimate structure of shells, communicated to the Royal Society, and others published in the ‘Annals and Magazine of Natural History,’ your long-continued work on Foraminifera, your communications on Oceanic Circulation and on Abyssal Life-forms, all testify to a life-long devotion to branches of natural knowledge bearing on that department of science the cultivation of which is the *raison d’être* of this Society.

I count it a pleasure, Dr. Carpenter, that it has devolved upon me to hand you this Medal.

Dr. CARPENTER, in reply, said:—

Mr. PRESIDENT,—

It is with no ordinary gratification that I receive from your hands the Medal of which the Council of the Geological Society has been pleased to think me deserving. For as the work of my life has been done almost entirely in the domain of biology, it has but incidentally brought me within the wide area covered by geological science. Although familiar from very early years with its great

fundamental ideas, and a deeply interested observer of its progress, I have never ventured to call myself a geologist. And it is therefore a distinction which I highly value, to be the recipient of so distinguished a token of appreciation on the part of those who are best qualified to judge of the importance of my work in its relation to geology.

This distinction is yet more gratifying to me from its having been founded by one whom I have held in the highest honour from my boyhood, when (as I well remember) I heard Charles Lyell spoken of as a young man who was advancing in the Geological Society doctrines of a most heretical kind, but was defending them so ably as to hold his own against the most weighty opponents. The study of his 'Principles' was not only the delight of my youth, but a most valuable part of my scientific training; and the privilege of subsequent intercourse with him through nearly forty years was one which I ever highly esteemed; for whilst it brought me under the immediate influence of his philosophic spirit, it also afforded me the continual stimulus of his kindly encouragement. I would recall a little incident which is doubly illustrative. When, in 1855, I made my monograph of the genus *Orbitolites* the basis of a disquisition on the general subject of the variability of species (a doctrine early impressed on me by Dr. Prichard), I sent him a copy of the memoir (published in the Philosophical Transactions), with a sort of apology for having tried to make so much out of what might be thought so small and trivial a subject; he replied with a most kindly approval of the object and manner of my work, adding "any single point is really the universe,"—a remark whose pregnancy left an impression on my mind that time has only deepened.

I cannot but esteem it a piece of singular good fortune that my association with my friend Prof. Wyville Thomson in the 'Lightning' Expedition of 1868, which was fitted out for the biological exploration of deeper sea-bottoms than had been then examined by the dredge, should have brought me into contact with a physical problem of the greatest interest, that of deep-sea temperature, and that the subsequent Expeditions of which the elucidation of that problem was a leading object have not only succeeded completely in all that it was hoped that they might accomplish, but have also brought back new and valuable data for the solution of one of the most fundamental questions of modern geology—the antiquity of the great existing distinctions between continental and oceanic areas.

In conclusion, I would assure the Geological Society that their generous recognition of my past labours will serve as an additional inducement to me to devote what may yet remain to me of time and ability to the completion of several researches, already far advanced, which will, I trust, be found to have no unimportant bearing on the future of geological science.

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## AWARD OF THE LYELL GEOLOGICAL FUND.

In presenting one moiety of the balance of the Lyell Geological Fund to Mr. P. HERBERT CARPENTER, M.A., the PRESIDENT addressed him as follows :—

Mr. P. HERBERT CARPENTER,—

The Council of the Geological Society, in awarding to you a portion of the balance of the proceeds of the Lyell Donation Fund, desires to express its sense of the great value of your researches into the structure and relationship of several families of fossil Echinodermata. Your papers "On some little-known Jurassic Crinoids," "On the Cretaceous Comatulæ," "On the Crinoids from the Upper Chalk," and that read last session, "On Hybocrinus, Baerocrinus, and Hybocystites," are models of clearness and an excellent earnest of future work. The Council hopes that this award may aid you in continuing those lines of research in which you have already achieved such signal success.

Mr. CARPENTER, in reply, said :—

Mr. PRESIDENT,—

It was with very great gratification that I heard from my valued friend and former teacher, Prof. Bonney, of the honour done me by the Council of the Geological Society in awarding me a portion of the Lyell Fund; and I am greatly indebted to you, Sir, for the kind way in which you have referred to my palæontological work. It has been done as a kind of recreation from the duties of a busy schoolmaster's life, and from the highly interesting but lengthy business of preparing the Reports on the 'Challenger' Crinoids. But I have always found that the few days which I have devoted to fossils during my holidays have sent me back to schoolwork and to recent Crinoids with renewed vigour, and often with fresh ideas. I have the strongest conviction (and many mistakes would be avoided were it a universal one) that the only way to understand fossils properly is to gain a thorough knowledge of the morphology of their living representatives. These, on the other hand, seem to me incompletely known if no account is taken of the life-forms which have preceded them. I have thus been led to carry on the two lines of work simultaneously; and I am happy to think that in the opinion of those best qualified to judge, I have been able to throw some light upon the study of the fossil Pelmatozoa.

In two respects I have been more than usually fortunate. My artist friends thoroughly understand their work; and the Council of the Society have always treated me with the utmost liberality in the very important matter of illustrations. For this and for many other acts of individual kindness on the part of the Fellows I gladly take this opportunity of expressing my warmest thanks to the Society.

The PRESIDENT then handed the second moiety of the balance of the Lyell Geological Fund to Prof. SEELEY, F.R.S., F.G.S., for transmission to M. E. RIGAUX, of Boulogne, and said :—

Professor SEELEY,—

In conferring upon M. Rigaux a portion of the balance of the proceeds of the Lyell Donation Fund, the Council of the Geological Society desires to signify its estimation of the value it places on his researches in the Jurassic formations of the Boulonnais and their contained fossils. In asking you to transmit to him this cheque, I would desire you to convey to him with it our hopes that he may continue those lines of inquiry in prosecuting which he has attained so great success.

Professor SEELEY in reply said :—

Mr. PRESIDENT,—

I feel that M. Rigaux deserves recognition for excellent stratigraphical work on the Primary and Secondary rocks of the country round Boulogne, and for careful descriptions of their fossils. But he is one of those modest men whose published writings represent but a small fraction of his knowledge, and who is far readier to deposit his collections in the public museum and to impart knowledge to scientific friends than to print his work. There can be but few geologists of our time who have visited the Boulogne country without being under obligations to M. Rigaux; and although, in a letter received from him, he speaks of this honour as being undeserved and unexpected, it is one for which he offers you his sincere thanks, and which will stimulate him to carry on those researches which have secured our esteem.

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#### AWARD OF THE BIGSBY GOLD MEDAL.

The PRESIDENT finally presented the Bigsby Gold Medal to Dr. HENRY HICKS, F.G.S., and addressed him in the following words :—

Dr. HICKS,—

The Council, in conferring on you the Bigsby Medal as a mark of their appreciation of your labours amongst the oldest fossiliferous and the Archæan rocks of Great Britain and Ireland, feels, in your community of interests, a peculiar fitness in associating you with the memory of the founder of this distinction. Your numerous communications, beginning with one “On the genus *Anopolenus*,” written in 1865, and culminating in that which you read at our last meeting, show to what good purpose you have employed the

*horæ subsecivæ* of a busy professional life in prosecuting those researches which have had a distinct effect on geological thought. In handing to you this Medal, I would express the wish that you will continue to prosecute the line of inquiry to which you have so long and so successfully devoted your leisure hours.

Dr. HICKS, in reply, said :—

Mr. PRESIDENT, —

I feel exceedingly grateful to the Council of the Geological Society for the great honour they have done me in selecting me to receive the Bigsby Medal; for I cannot fail to recognize in this award a recognition by those whose opinion I most value, that work which has long been to me a means of recreation and of much intellectual enjoyment has also yielded something towards the advancement of that science to which I am so deeply attached. I must also express my gratitude to you, Sir, for the kind manner in which you have referred to my labours. It is just 20 years since I commenced my search for fossils among the old rocks at St. David's, and the enthusiasm with which every new find was welcomed by the late eminent palæontologist Mr. Salter, to whom they were first sent, was in itself a sufficient stimulus for any exertions required.

I had the honour also from time to time to conduct many eminent geologists over the ground explored, and received from them much encouragement. Among these, however, no one was more anxious to show enthusiastic sympathy than the amiable Dr. Bigsby, the founder of this Medal, who visited St. David's in the summer of 1866. His interest in the sections was extreme, due doubtless in part to the fact that a few years before he had communicated a paper to this Society on the relation between the Cambrian and Huronian rocks, and that here at St. David's I was able to show him some proof in support of the view which he maintained, that the Huronian rocks were older than any which could be classed as Cambrian in America.

It is therefore, Sir, peculiarly pleasing to me that I should now be thought worthy of the great honour of receiving the Bigsby Medal; and I can only hope that I may be able, in the words of the founder, to do further work, and to continue with renewed vigour those researches which have brought me this honour and what I value almost equally, namely the friendship of so many eminent Fellows of the Geological Society.

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## THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

J. W. HULKE, Esq., F.R.S.

In compliance with a time-honoured custom in our Society which bids us at this, our annual gathering, not leave unnoticed, as if forgotten, the memories of those of our Fellows whose names death has taken from our roll during the past year, I begin this address with the usual obituary references to those whose works have stamped their features more deeply on our recollection.

Taking their names in alphabetical order, the first whose loss we lament is the late Prof. A. LEITH ADAMS, M.A., of Queen's College, Cork, elected a Fellow in 1870. He was a good example of a band of earnest students in the ranks of the Army Medical Department who have made good use of the opportunities afforded them on service in every quarter of the globe to cultivate an acquaintance with Nature. His works, amongst which may be mentioned 'Wanderings of a Naturalist in India, the Western Himalayas, and Cashmere,' 'Notes of a Naturalist in the Nile Valley and Malta,' and 'Field and Forest Rambles in Eastern Canada,' show that he was no laggard in the pursuit of natural history. His contributions "On the Occurrence of Fluviatile Shells at High Levels in the Nile Valley," and on "Miocene Vertebrate Remains from Caves in Malta," are published in our Quarterly Journal; but his chief work is his memoir "The British Fossil Elephants," in the Palæontographical Society's Transactions. In 1872 he was elected F.R.S. After his retirement, with the rank of Deputy Surgeon-General, from active service with the army, he held professorships in zoology and natural history in Dublin and in Cork. His death occurred in August last.

On Thursday the 20th of April there fell asleep in the ripeness of his years, in his quiet country home at Down, in Kent, CHARLES DARWIN, a man whose life and work it is impossible faithfully to portray within the brief compass of an obituary notice. This, in his case, is less to be regretted, since to him in an especial degree are applicable those significant words, "He being dead yet speaketh." Endowed with a splendid intellect, a rare nobleness of character, and the most intense love of truth, he devoted a long life to the development of those pregnant principles of "Evolution" the enunciation of which at first drew down upon him so much opposition, but which he had the rare happiness to live to see generally accepted. His most striking qualities were his wonderful patience in the accumulation of facts (no labour was too great, nothing appeared too minute or too trivial for his attention, no suggestion from another seemed unworthy of his consideration), his judicial impartiality (evidenced in his temperate statement of facts and inferences, and his admirable



candour in setting out the objections which could be urged against them), and his tolerance of the prejudices of others when he knew them to be earnestly seeking after truth.

Born at Shrewsbury, on the 12th of February 1809, he appears to have received his early training in the celebrated Grammar School of that town.

In Edinburgh he began the study of medicine (in which profession his father had attained considerable eminence); but having no natural inclination towards it he abandoned it and entered the University of Cambridge, where, under the genial teaching of Prof. Henslow, that love of Nature was kindled in his mind which never after ceased to animate it, and which bore such splendid fruit. In 1831, through an introduction by Prof. Henslow, he began, as naturalist in H.M.S. 'Beagle,' that voyage to the southern hemisphere of which eight years later, being then a Secretary of this Society, he gave so charming an account in his "Journal" of the voyage, one of the most fascinating books ever written. Elected a Fellow of our Society in 1836, one of his first contributions, read on 1st November, 1837, "On the Formation of Vegetable Mould through the agency of Earth-worms" (the subject of the last work which issued from his pen), bore the same stamp of carefulness and thoroughness which characterized all his writings. In 1841 he contributed a valuable paper "On the Distribution of Erratic Boulders and on the Contemporaneous Unstratified Deposits of South America," in which he showed good grounds for attributing these to the agency of floating ice. His memoir "On the Structure and Distribution of Coral Reefs" contained views on the origin of atolls, before little understood, which quickly gained general reception; and his observations on the volcanic islands visited during his voyage in the 'Beagle' witness how closely and carefully he studied their natural phenomena. His 'Geological Observations,' published in a collective form in 1867, should be read by all. In later years his attention was turned towards those lines of work with which his memory will ever be connected; but to the close of his life it is well known that he never ceased to feel a deep interest in our branch of natural science and in this Society. The magnificent homage paid to his remains was a fitting sequel to so glorious a life.

At St. Leonards-on-Sea, in the 86th year of his age, died, in the second week of August, Sir WOODBINE PARISH, K.C.H., F.R.S. Elected a Fellow of the Geological Society in 1832, Sir Woodbine, then W. Parish, Jun., having previously, when H.M. Chargé d'Affaires and Consul-General at Buenos Ayres, presented to the Society some valuable fossil remains of Mammalia, communicated in the year of his election an account of fresh discoveries which added greatly to our knowledge of the *Megatherium* and *Glyptodon*. In 1838 he communicated two papers on collections of fossils made by him at Bognor and Hastings. He rose to the office of Vice-President of our Society, and to the close of his life ever took a lively interest in its welfare.

On the 16th of March, at Makouw's Vlei, on the Vaal, in South Africa, died G. W. Stow, who had contributed probably more than any other person towards a thorough geological exploration of those parts of the African continent comprised in our own dominions and the Free States. Mr. Stow's work was carried on under circumstances of such continued pecuniary difficulty and personal hardship as nothing but the sacred fire of a pure love of investigation for its own sake, rather than for any monetary emoluments which might ultimately accrue from it, would have enabled him to endure, though a man of exceptionally strong character and great physical strength. But the strain finally proved too great, and he succumbed at a moment when success seemed almost within his grasp. He leaves a widow and five young children, in very destitute circumstances, to lament his loss.

Elected a Fellow in 1872, he contributed papers on the geology and fossils of South Africa, which were published in our Journal. But the work to which he devoted his best years and energy is still in manuscript. It is greatly to be desired that this should find a publisher.

Sir CHARLES WYVILLE THOMSON, born in 1830, had only just completed his fifty-second year at the date of his death on the 10th of March last. Beginning the study of Medicine at the University of Edinburgh in 1845, he soon found himself attracted rather to its scientific than to its practical side; and in 1853 he was appointed to the vacant lectureship in Botany in King's College, and later in Marischal College at Aberdeen, from which University he received the degree of LL.D. when he had scarcely attained his majority. He subsequently held lectureships on botany, zoology, geology, and mineralogy in the Queen's Colleges at Cork and Belfast and in the University of Edinburgh, where he had the reputation of being an able teacher. Attracted particularly to the class Echinodermata, and especially to the order Crinoidea, he communicated, in 1863, to the Royal Society a paper "On the Embryology of *Antedon (Comatula) rosacea*." Later he went to Norway, at the instance of Prof. Sars, to study the living Apiocerinoid now known as *Rhizocrinus lofotensis*, the exhibition of which in scientific circles by his friend Dr. Carpenter principally led to the deep-sea dredging expeditions of H.M.S.S. 'Lightning' and 'Porcupine,' in which, in conjunction with Dr. Carpenter and Dr. Gwyn Jeffreys, Sir. C. W. Thomson took an important part. The latter expedition laid the foundation for the solution of many questions of the highest interest to physical geography and geology, by demonstrating that there is practically no limit to the depth at which marine animals may exist. Not only was the true temperature of the deep-sea bottom then first ascertained, but the temperature at different depths was worked out. Many marine types, especially of Echinoderms and Siliceous Sponges, procured by dredging, distinctly represented Cretaceous forms; and, further, the *Globigerina*-mud, which covers the Atlantic bed to an unknown thickness, was proved to correspond in many points with

the Old Chalk. On these facts, in conjunction with the absence of evidence of a general upheaval of the continents which border the Atlantic basin since chalk rose into dry land, Prof. Thomson erected the bold hypothesis that the present deep-sea basin of the Atlantic has been such during the entire Tertiary period, and that the *Globigerinæ* now living are the lineal descendants of those of the Cretaceous epoch.

The last loss which it is my sad duty to record is the death of EDWARD BERNARD TAWNEY, which occurred at Mentone on the 30th December, in the 42nd year of his age. From boyhood he showed a great inclination towards natural science. He passed with distinction through the School of Mines. He travelled much; he was a close observer and a clear writer. Our Quarterly Journal is enriched by several valuable contributions from his pen, which are all stamped by an intense love of truth. In 1878 he was appointed Assistant to the Woodwardian Professor of Geology; and during the last months of his life he was engaged upon a description of the fine series of rocks collected by Sedgwick. Mr. Tawney's career was an admirable instance of successful work achieved in spite of a frail and suffering frame.

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Upon a review of the work done by the Society during the sessional year which has just closed, it appears that the number of papers read slightly exceeded the average and, if I may venture an opinion on such a matter, they maintained the standard of former years.

The relatively large number treating directly of, or referring incidentally to, drift and gravels is suggestive that, in connexion with these and their associated organic remains and implements, there is still much deserving the attention of the investigator who aspires to assist in clearing away the ambiguities which, in particular instances, yet exist with respect to the sources, the modes of distribution, the age, and the general bearings of these deposits. The once widely accepted canon that the lower are invariably newer than the higher beds of such deposits has been lately shown not to be universally applicable by a discovery in the Sablières de Chelles-sur-Marne, near Paris, where in the lowest of three terraces of gravel only a little above the present level of the river, a much older fauna has been found than that yielded by the highest terrace in the same valley, and this under conditions which appear to forbid a remaniement.

*Ice*, to judge by the number of papers relating to it, and the hot discussions these provoked, appears still to exercise an undiminished fascination; and we have lately heard repeated, and enforced by fresh illustrations, arguments against the power of glaciers to excavate rock-basins, a faculty which not many years since few geologists seriously questioned.

On *petrology* seven papers only were read. One of these recorded



a rough experiment made in the field to test the comparative specific gravity of solid and molten lava. Another related to the occurrence of diamonds in S. Africa in volcanic rock at a greater depth than the superficial shales through which it had burst, a fact at variance with the hypothesis advanced by a previous author that the diamonds were derivatives of the hydrocarbons contained in the shales.

*Micro-petrology.*—Five petrological papers dealt with the intimate structure of rocks, a number which appears small considering the activity with which the microscopic investigation of rocks has been pursued during the three decades which have elapsed since the great impulse given to this branch of research by Dr. H. C. Sorby's paper "On some Peculiarities in the Microscopic Structure of Crystals applicable to the determination of the Aqueous or Igneous Origin of Minerals and Rocks," published in the Society's Journal in 1851. Since that epoch petro-microscopy has attained an importance that can hardly be overestimated. Each successive year has yielded fresh evidence of its value, which has, perhaps, seldom been more aptly illustrated than in Prof. Bonney's paper "On the Hornblendic and other Schists of the Lizard District," a locality which the labours of one of our founders, who was also one of the fathers of the Geological Survey of the United Kingdom, Sir Henry De la Beche, have rendered classic ground.

Amongst the *stratigraphical* papers, probably second to none in interest were:—"A Comparison of the Cambrian Strata of the Russian Baltic Provinces with those of Scandinavia and Great Britain," by Dr. F. Schmidt, in which he argued for the unbroken continuity, in those provinces, of the Cambrian, Ordovician, and Silurian Systems; Prof. Lapworth's comprehensive and elaborate memoir "On the Girvan Succession," in which he offered a demonstration of the true successional order of the Girvan series of Palæozoic rocks, based principally on their fossil contents. Should this new reading of the Girvan beds stand the tests of time and adverse criticism, its author may well find satisfaction in having achieved a success which many other able workers in the same field failed to secure; and, lastly, Dr. Hicks's paper "On the Metamorphic and Overlying Rocks in parts of Ross and Inverness Shires (with petrological notes by Prof. Bonney)," in which the author offers a demonstration, based on stratigraphical and petrological evidence, that the large group of rocks in those districts, hitherto regarded as metamorphosed Silurian, are really members of the much earlier Archæan system. The question is one of much importance; and, however it may be finally settled, it is a matter of congratulation that it has engaged the attention of so earnest a worker, and one whose labours amongst the earliest crystalline rocks in other districts have been deemed to merit the Bigsby Medal.

An analysis of all the subjects treated of during the Session has brought out what perhaps might not be generally anticipated, a great preponderance of *paleontological* papers. Their number actually exceeds that of those on stratigraphy and topography and



dynamics, and it is much greater than the total of all relating to other branches of our science.

Two only of the palæontological papers were *botanical*, a small proportion considering the general possession of some acquaintance with the forms and distribution of living plants, the great attractiveness of fossil botany, the information respecting former climates deducible from it, and the accessibility of such rich floras as those of the Tertiaries in the Isles of Wight and Sheppey. The fact that one of the papers related to plants discovered in Wealden rocks near Hastings leads me to call attention to the profusion of vegetable remains in the blue Wealden clays in the neighbourhood of Chilton.

Of seventeen zoological papers, ten referred to Invertebrata. One of these, by Dr. Häusler, embodied the results of a very laborious study of the *arenaceous Foraminifera* of the Swiss Jurassic rocks, of which he had determined about sixty species. It is interesting that whilst not a few of these range back to Permian and Carboniferous times, most of them closely resemble recent deep-sea species and varieties, yet similar forms have not hitherto been found in the newer rocks. A paper by Mr. P. H. Carpenter on certain Silurian Crinoids, about which there had been previously much difference of opinion, added greatly to our knowledge of the structure and affinities of these obscure and interesting Echinoderms.

*Bryozoa* ranging from Palæozoic to Pliocene formed the subjects of three papers.

Six communications were received on *Corals*, of which two by Mr. Tomes showed how largely our knowledge of the fauna of particular stages can be increased by residents in their neighbourhood who can take advantage of every fresh exposure of rock. The singular beauty of their outward forms, and the admirable symmetry of their internal structure, ever make corals attractive objects of study; whilst their limitation by circumstances of depth, of temperature, and of purity of water (which it is reasonable to infer had the same influence in past as in present time) has been regarded as affording valuable information respecting the physical geography of the regions in which their remains occur. Recent discoveries have proved, however, that their occurrence is less restricted by depth of water than was formerly supposed.

Two papers only were devoted to *Mollusca*; but one of these, in which Lieut.-Col. H. Godwin-Austen identified an Eocene shell from Sheppey with a living genus now restricted to India, was of great interest.

The remaining seven zoological papers treated of vertebrate remains. In one of them Prof. R. Owen described an imperfect thigh-bone which he referred to *Nototherium*, an extinct Australian Marsupial in some points resembling the existing Wombats. The six others related to fossil Reptilia.

Two of the most important of these were a paper by Prof. H. G. Seeley, "On *Neusticosaurus pusillus* (Seeley), *Simosaurus pusillus* (Fraas)," and a paper by Prof. R. Owen "On Generic Characters in the Order Sauropterygia."

Of *Neusticosaurus pusillus* Prof. H. G. Seeley says, "it is probably the smallest representative of the Plesiosauria yet exhumed; but it has the greater interest in exhibiting in the hind limbs all the characters of a land animal, while the fore limbs have become paddles, in which a more striking approximation is made to *Plesiosaurus* than was previously known in any Triassic representative of this order." Connecting links are so important that it is to be hoped that before long the acquisition of less imperfect material than that at Prof. Seeley's command may confirm his views, and afford additional information respecting this highly interesting Sauropterygian.

Prof. R. Owen's paper "On Generic Characters in the Order Sauropterygia" must command the attention and consideration due to the mature opinion of so eminent an anatomist and zoologist, who has made fossil reptiles a special study, and is the founder of the order to which his paper relates.

The subclass Enaliosauria (Owen), which includes the subjects of both the above papers by Profs. Seeley and Owen, is in several respects one of much interest.

This Society may be said to have a sort of property in it, because it was at one of its meetings, some sixty years ago, that Conybeare and De la Beche first made known the *Plesiosaurus* and also added largely to the previously comparatively scanty knowledge of *Ichthyosaurus*. Their admirable memoir, printed in vol. v. ser. i. of the Society's Transactions, published in 1821, supplemented by two others which shortly followed it, was so comprehensive that to the illustrious Cuvier it appeared to leave little to be added by subsequent investigators. Since then, however, large quantities of Enaliosaurian remains have been accumulated (a magnificent series of their skeletons is now displayed in the galleries of the new Museum of Natural History in Cromwell Road, and few of the provincial museums of any magnitude are without examples of them); and yet many questions concerning these old "Sea-Dragons," as Thomas Hawkins quaintly called them, continue to this day unsettled.

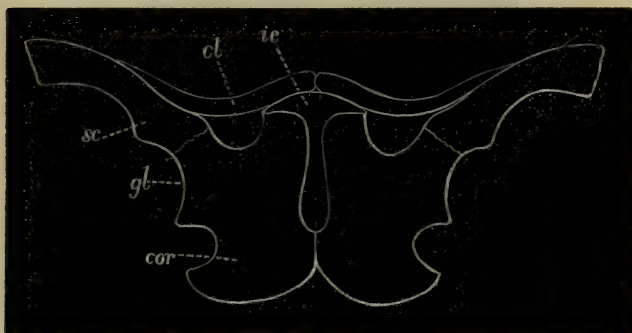
Thus taxonomists differ much as to the true zoological position of the Enaliosauria. Prof. R. Owen, the founder of this subclass, places it between Labyrinthodonta (Batrachia) and Anomodontia; whilst Claus, the author of one of the newest works on systematic zoology having a wide reputation, makes Enaliosauria the first order in a subclass Hydrosauria (in which he includes Crocodilia) which he intercalates between Sauria and Chelonia. Claus's order Enaliosauria comprises three families, Ichthyosauria, Plesiosauria, and Nothosauria. Prof. R. Owen's subclass Enaliosauria contains his two orders Ichthyopterygia and Sauropterygia. The former is represented in our rocks, as yet, only by the genus *Ichthyosaurus*; whilst the latter comprises the four genera *Plesiosaurus*, *Pliosaurus*, *Nothosaurus*, and *Placodus* (*Neusticosaurus* would also find its place here).

As a preliminary to discussing the systematic position of the Enaliosauria, the question whether the alliance of the orders Ichthyopterygia and Sauropterygia is a natural one requires examination.

Are there discernible in the members of these two orders such structural resemblances as command our assent to their common ancestry?

Disregarding *Placodus*, as too imperfectly known, and limiting the comparison to the elements of their shoulder-girdle and limbs, or, in Prof. Owen's words, to their "sterno-coraco-scapular frames" and limbs, there are present, in all the genera of each order in which these parts are known, two pairs of bones the essential nature and identity of which are undoubted, the coracoids and scapulæ.

Fig. 1.—*Shoulder-girdle of Ichthyosaurus, ventral view.*



*cl*, the clavicle; *ic*, the interclavicle; *sc*, the scapula; *cor*, the coracoid;  
*gl*, the glenoid fossa.

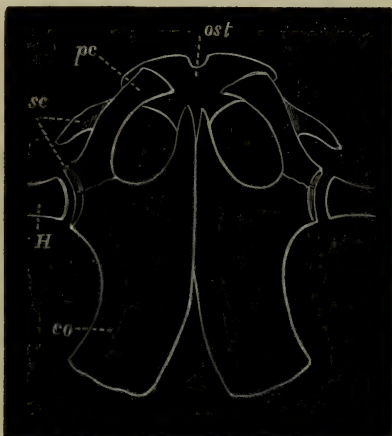
In *Ichthyosaurus* (fig. 1) the coracoids are relatively broad, and they are deeply notched in front and behind the glenoid fossa. In the typical *Plesiosaurs* (as *P. dolichodeirus*) (fig. 2) the coracoids are long and narrow. In Cope's subgenus *Elasmosaurus*, as also in *P. Manseli*, Hulke, and *Colymbosaurus*, Seeley, which are evidently closely related to it, the bony coracoid is broad, but of relatively small antero-posterior extent, and it sends backwards from the postero-external angle a wing-like process or cartilage leaving a vacuity perhaps subtended by membrane.

In *Nothosaurus* a deep narrow notch separates a long square process in front of and internal to the glenoid part of the bone, which a constriction divides from a large rhomboidal expansion that meets the other coracoid in the middle line. Yet under these diversities of form, the true homology of the coracoid is too plain to be missed; and this is equally true of the scapula, to which I shall presently return. *Ichthyosaurus*, our sole representative of the order Ichthyopterygia, has in its shoulder-girdle a third pair of bones, by general consent clavicles. Are these bones present in the Plesiosaurian shoulder-girdle and in that of the other genera of Sauropterygia? Some anatomists answer this affirmatively, finding clavicles in *Plesiosaurus* (fig. 2) in that piece which extends forwards and inwards from the glenoid part of the scapula to the median azygos bone reputed episternum or interclavicle, and they consider that in this genus the clavicle is confluent



with the scapula. This interpretation seems to be supported by an analogous bar in the amphibian shoulder-girdle. This, considered

Fig. 2.—*Shoulder-girdle of Plesiosaurus (type), ventral view.*



*ost*, the omosternum; *pc*, the præcoracoid; *sc*, the scapula; *co*, the coracoid; *H*, the humerus.

præcoracoid by W. K. Parker, regarded as clavicle by Wiedersheimer, thought to comprise both præcoracoid and clavicle by Hoffmann, is primitively a simple cartilaginous rod extending ventrally from the scapula towards the middle line of the body. Later, an ectosteal splint forms on its front border, and, growing, more or less sheathes it, the rod itself meanwhile undergoing a variable amount of endosteal ossification; and when these two processes of ossification are completed, a slight longitudinal furrow may be the only trace of the dual origin of the bar. It is evident that the ectosteal splint alone can have any pretension to homology with the clavicles of higher vertebrates; and I imagine that its intimate association with the cartilaginous rod (which is segmented off by longitudinal fissure from the coracoid and is therefore unmistakably præcoracoid) was one of the considerations that led Prof. Parker to regard the bar in its entirety as præcoracoid, and to deny the occurrence of true clavicles in Batrachia, a view which has much in favour of it. In Chelonia (fig. 3), however, the ambiguity, so puzzling in Batrachia, disappears. They also have a similarly placed ventral bar, which, except in very immature individuals, is (as in *Plesiosaurus*) confluent with the glenoid part of the scapula, from which it extends inwards towards the middle line of the body. Early comparative anatomists regarded this as an acromion or clavicle, the view, I think, still held by Prof. R. Owen. Of its homology with the analogous bar in *Plesiosaurus* and *Nothosaurus* I myself have no doubt; and if it be clavicle in the Chelonian it is so in *Plesiosaurus* and *Nothosaurus*, and thus clavicles would be present in Sauropterygia as in Ichthyopterygia. But in Chelonia, as Prof. W.



K. Parker has shown, the true clavicles are to be found in the episternal elements of the plastron (dermal ossifications); the reputed

Fig. 3.—*Shoulder-girdle of Chelone mydas, dorsal view.* (Slightly altered, after Parker.)



*cl*, the clavicle; *ic*, the interclavicle; *pcr*, the præcoracoid; *c*, the coracoid.

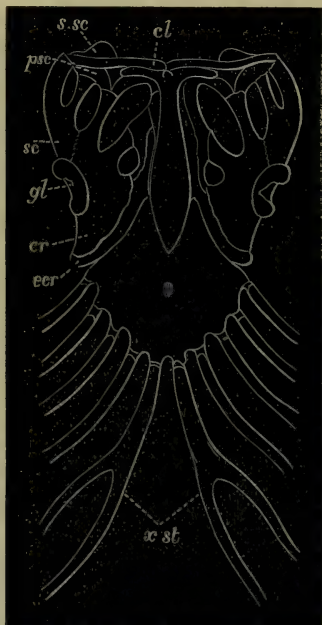
clavicles, which are parts of the cartilaginous endoskeleton, are then the præcoracoids; whence it follows that there is a degree of probability, almost amounting to proof, that the corresponding bar in *Plesiosaurus* is also præcoracoid, and thus evidence of the presence of true clavicles in this genus and, I may add, *Nothosaurus*, fails; so that in the present state of our knowledge on this point we are warranted in considering clavicles to be wanting in *Sauropterygia*.

There remains for comparison one more piece, the azygos median bone called episternum or interclavicle.

In *Ichthyosaurus* (fig. 1) this T-shaped bone so closely agrees in its form and its relations with the interclavicle of existing Lizards and Chelonia that its homology with this is unimpeachable. Can the same be maintained of the analogous piece in the shoulder-girdle of *Plesiosaurus*? I submit that its homology with the lacertilian interclavicle is more than doubtful. The Lizard's interclavicle is a membrane bone; it lies superficially (fig. 4). In *Ichthyosaurus*, as in extant Lizards, it lies at the under surface of the other (endoskeletal) elements of the girdle. In *Plesiosaurus* (fig. 2) the reputed clavicle lies above the præcoracoids and coracoids, upon their upper or visceral surface,

and some examples show traces of a primitive composition of two similar halves. These are circumstances, particularly the former,

Fig. 4.—*Lacertilian Shoulder-girdle, ventral view.* (After Parker.)



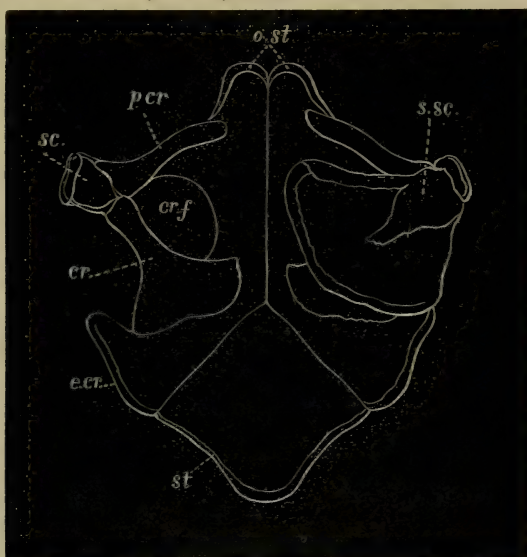
*xst*, the xiphisternal; the other letters as in the preceding figures.

which appear to me to challenge its title to being a true interclavicle. But if not interclavicle, is there any known skeletal element with which it may be identified? I suggest that the omosternum (W. K. Parker) of existing Batrachia (figs. 5, 6) is such an element. This, often confounded with the true interclavicle (of Lizards), is shown by Parker to consist primitively of two pieces, each segmented off from its corresponding epicoracoid, which later coalescing form the azygos keystone of the arch. Its origin as a cartilaginous endoskeletal part forbids the identification of the Batrachian omosternum with the interclavicle of Lizards and Chelonia.

In the extant Australian Batrachian *Calamites cyaneus* (fig. 6), the omosternum is represented by Parker as permanently retaining traces of its primitive duality, and sending backwards from each half a small plate on the deep aspect of the præcoracoid. Its deep position together with indications of an originally dual composition are, I submit, good grounds for assigning a high degree of probability to the homology of the median element of the shoulder-girdle in *Plesiosaurus* with the Batrachian omosternum. So far, then, as our present knowledge allows an opinion, we are warranted in considering

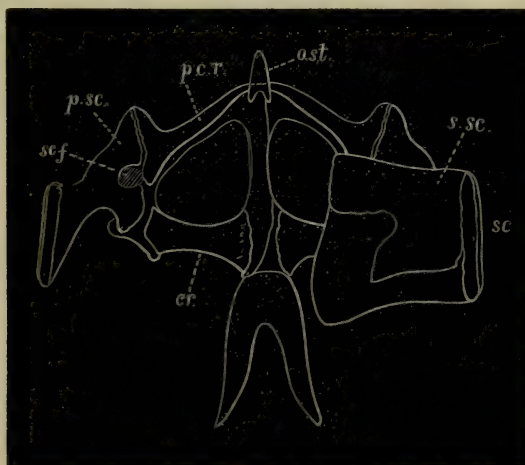
that a true interclavicle as also true clavicles, both present in Ichthyopterygia, are absent in Sauropterygia.

Fig. 5.—*Shoulder-girdle of Pipa dorsigera*. (After Parker.)



*o.st.*, the omosternum; *sc.*, the scapula; *s.sc.*, the suprascapula; *p.cr.*, the praecoracoid; *cr.*, the coracoid; *cr.f.*, the coracoid foramen; *e.cr.*, the epicoracoid; *st.*, the sternum.

Fig. 6.—*Shoulder-girdle of Calamites cyaneus*. (After Parker.)



*o.st.*, the omosternum; *p.c.r.*, the praecoracoid; *sc.*, the scapula; *s.sc.*, the supraclavicular; *sc.f.*, the scapular foramen; *cr.*, the coracoid.

Time will not allow me to weigh all the points of agreement and difference present in the axial skeletons of the representative members of these two orders; and I must limit myself to the expression that the difference appears to me so great that, in view of them, it is difficult not to regard the association of Ichthyopterygia and Saurropterygia in one subclass as a taxical convenience, rather than as expressive of a direct common ancestry. For such common ancestor it would be requisite to go very far back. Gegenbaur hints that the Enaliosauria came off from the vertebrate stem before the Batrachia (Labyrinthodonta).

The confusion which, for some time at least, almost invariably follows the dissolution of a generally accepted taxis, and the convenience of the association of the two orders, recommend the present retention of this subclass; and upon a review of all the evidence, the zoological position assigned to Enaliosauria after Amphibia by Prof. R. Owen appears to be the best yet proposed.

In our rocks the order Ichthyopterygia is, as already mentioned, represented, I believe, only by the genus *Ichthyosaurus*; for the propodial\* bone on which Prof. H. G. Seeley founded the Ichthyosauroid genus *Cetarthrosaurus* (*C. Walkeri*) agrees so closely with the humerus of *Platycarpus*, Cope, in those very points wherein it deviates from the Ichthyosaurian pattern, that I think *Cetarthrosaurus* should be removed from Ichthyosauria into Cope's subclass Pythonomorpha. In saying this I must guard myself against being understood to imply that I regard this subclass as a valid one. In North-American rocks the Ichthyopterygia include *Sauranodon*, Marsh, which has a close general resemblance to *Ichthyosaurus*, but is remarkable for being toothless.

The geographical distribution of *Ichthyosaurus* was very wide. Remains of one species were brought home by the North Polar Expedition under Sir E. Belcher from the islands between West Cornwall and North Devon, and vertebræ with portions of paddles of two very distinct species were discovered in Spitzbergen by the Swedish Expeditions in 1864 and 1868, under A. E. Nordenskiöld; while fossils in the British Museum and in the Museum at Christchurch, New Zealand, attest the occurrence of the genus as far south as the 45th parallel of south latitude. In Europe the number of species, as of individuals, appears to have been very great. It is probable, however, that a critical review would much reduce them; for there is great difficulty in seizing upon good specific characters. These Thos. Hawkins found in the shape and number of the mesopodial (carpal or tarsal) bones and phalanges; and on this basis he constructed the singular nomenclature used in the 'Book of the Great Sea-Dragons' and the 'Memoirs of *Ichthyosauri* and *Plesiosauri*,' a nomenclature not the least wonderful of the many singularities to be found in those very remarkable folios. The uncouthness of such words as *Chiroparemekostinus*, *Chirostrongulostinus*, *Chirilogostinus*, *Chiropolyostinus* was so repellent that it cannot surprise us that they never secured acceptance.

\* The term applied by Prof. O. C. Marsh indifferently to the humerus and femur.



Prof. R. Owen, who has described the greater number of species found in British rocks, has employed for their distinction chiefly the form of the teeth, the proportion of the length of the snout to that of the rest of the head, and the proportionate length of the head to that of the vertebral column. The well-known difference of length of the snout in the same species of extant crocodiles in immature and mature individuals suggests caution in the use of such proportionate length as specific characters for *Ichthyosauri*, since the criteria for inferring the age are less trustworthy in Reptiles, where many sutures and cartilaginous parts of the skeleton persist as such throughout life, than they are in higher Vertebrata, where they disappear with maturity, and their presence is a stamp of immaturity.

As regards their distribution in time, Enaliosauria, as is well known, range from the Lias to the Chalk inclusive, where they appear to have become extinct; unless the survival of one species of *Ichthyosaurus*, *I. gandavensis*, in early Tertiary times be confirmed by fresh evidence.

To the question of greatest moment to the stratigraphist, whether particular species of *Ichthyosaurus* and *Plesiosaurus* can be safely taken as stamping particular geological horizons, I must reply that our present knowledge does not appear to me to justify this use.

I have referred to the difficulty in seizing good specific characters for *Ichthyosauri*. A similar difficulty is felt with respect to the members of Conybeare's original genus *Plesiosaurus*. Prof. H. G. Seeley, in a suggestive paper read 24th Nov. 1874, and printed in the Quart. Journ. Geol. Soc. vol. xxx. p. 436, showed the existence of certain well-marked differences in the form and proportions of the elements of the shoulder-girdle, and, assigning to these a generic value, he broke up the original genus into several subgenera, of which *Colymbosaurus* and *Ophthalmosaurus*, *Murænosaurus* and *Eretmosaurus* may be cited as examples.

From 1821, the date of Conybeare and De la Beche's paper to which allusion was recently made, until 1841, the genus *Plesiosaurus* was the only representative of the order Sauropterygia discovered in British rocks. In 1841, Prof. R. Owen removed out of this genus two species, *Plesiosaurus grandis*, Owen, and *P. trochanterius*, Owen, and made for them the new genus *Pliosaurus*. The fossils on which this genus was first founded were two propodial bones, of which one, preserved in the British Museum, was originally in the collection of the Earl of Enniskillen, then Viscount Cole; and the other, preserved in the Museum at Dorchester, was obtained by J. C. Mansel, now J. C. Mansel-Pleydell, Esq., in Kimmeridge Bay. To the generic characters furnished by these fossils others, supplied by teeth and cervical vertebræ, were subsequently added. Still later, in a paddle from the Portland quarries, Prof. R. Owen found another generic character of *Pliosaurus*, the presence of a third bone in the second segment of the limb corresponding to the cnemion or antibrachion (leg or forearm) of higher vertebrates. Lastly, in his paper lately read here, Prof. R. Owen makes known another generic character of *Pliosaurus* in the presence of a dorsad

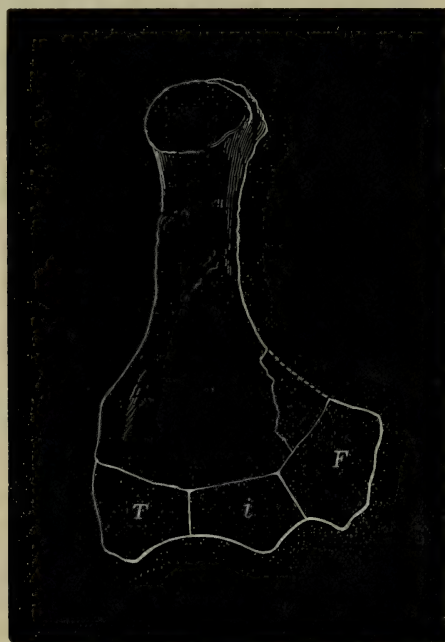
and laterad extension of the scapula corresponding to the blade of the scapula of other vertebrates, which he considers to be absent in *Plesiosaurus*.

Recapitulated in the order in which they were enunciated, the generic characters of *Pliosaurus* are those furnished, 1, by the propodials (femora or humeri); 2, by the cervical vertebræ; 3, by the teeth; 4, by the cnemial or antibrachial (epipodial, O. C. Marsh) segment of the limbs; and, 5, by the "sterno-coraco-scapular frame."

In estimating the generic value of these several characters, it should be borne in mind that no evidence is adduced that any of the remains on which they were based were found so associated as to warrant the belief that they formed parts of the same skeleton; indeed circumstances show that such was not the case. This is certainly true of the two type femora of *Pliosaurus grandis* and *P. trochanterius*, of the paddle of *P. portlandicus*, of the sterno-coraco-scapular frame, and, I think, also of the vertebræ and teeth. It should also be mentioned that the two fine skulls presented to the British Museum by J. C. Mansel-Pleydell, Esq., and referred by Prof. Owen to *Pliosaurus grandis* and *P. trochanterius*, are dissociated fossils.

It is evident that a series of generic characters drawn from such dissociated remains can have only a hypothetical value.

Fig. 7.—*Hind limb of Plesiosaurus Manseli.*



T, the tibia; i, the intermedium; F, the fibula.

In a paper read here on 27th of June, 1870, descriptive of a large series of remains which, by their close association, were thought by Mr. Mansel-Pleydell, under whose personal supervision they were exhumed, to form one skeleton, that of a long-necked Plesiosauroid (*P. Manseli*, Hulke), attention was drawn by the author to the close resemblance of the humerus of this saurian to the type specimen in the British Museum labelled "No. 31,975. Femur, *Plesiosaurus* (later *Pliosaurus*) *trochanterius*, Owen," their similarity being so great as to favour their generic and perhaps specific identity. The striking resemblance of the femur also of *Plesiosaurus Manseli* to the type fossil in the British Museum labelled "No. 31,787, a femur of *Pliosaurus brachydeirus*," was also noticed. The presence of a third bone in the second segment of the limb was demonstrated in *Plesiosaurus Manseli* (fig. 7), and shown not to be peculiar to *Pliosaurus* (*P. portlandicus*). It should be remembered that the paddle of *Plesiosaurus Manseli* was identified as such by its association with other parts of the skeleton, which was indubitably that of a long, slender-necked Plesiosauroid; whilst the paddle of *Pliosaurus portlandicus*, bought of a dealer (Mr. Smith of Weymouth), had been obtained by him from quarrymen, and it was not found with other remains, such as the teeth or cervical vertebræ ascribed to *Pliosaurus*. Later the British Museum obtained from the same dealer some trunk-vertebræ which may have come from the same spot where the paddle was found; but there is nothing decisive of this, and trunk-vertebræ have not the same typical value as cervical.

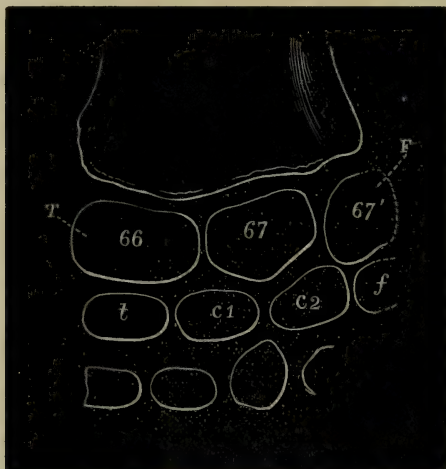
From this I think it will be apparent that proof is yet wanting that the form of paddle ascribed to *Pliosaurus* is really Pliosaurian; whilst there is evidence that such paddles were actually possessed by *Plesiosaurus Manseli*.

A very interesting question, and one having a much wider morphological bearing than in relation to Sauropterygia, is the homology of the third bone in the epipodial segment of the paddle\*. This (marked No. 67'. figs. 1, 2, pl. iv., in his memoir on *Pliosaurus portlandicus*) Prof. Owen regards as the homologue of the fabella present in some *Plesiosaurs* (*P. rugosus*), "where (he says) its homotype in the fore limb is represented by a detached olecranon process of the ulna." The first two ossicles in the figure of the Portland paddle referred to, counted from the tibial (or radial) border, are numbered by Prof. Owen 66, 67, the numbers by which he always denotes the tibia and fibula; and he continues, "whether to regard the ossicle marked 67' as the apophysial lever of the fibula or as the calcaneum may be a question. The ossicle marked 67', in the Portland paddle

\* Recent investigators, amongst whom I must particularly mention Gegenbaur, have shown that the carpus or tarsus (mesopodium, Marsh) of all Vertebrata is constructed upon a common plan, however greatly this may be hidden under external diversities of form, and that it consists of a proximal row of three bones, of which two are named respectively, from their relation to the bones of the forearm and leg (or the epipodium), os radiale, os ulnare, os tibiale, os fibulare; of an intermediate ossicle, os intermedium; of a distal row of ossicles in number corresponding to the digits; and, lastly, of one or two ossicles placed centrally between the proximal and distal rows, ossa centralia.

(fig. 8), is, I suggest, neither "the apophysial lever of the fibula," nor "the calcaneum," nor yet "a detached olecranon," but it is the fibula

Fig. 8.—*End of Femur, Epipodial and Tarsal Bones of Pliosaurus portlandicus, Owen.* (From a plate in the 'Fossil Reptilia.')



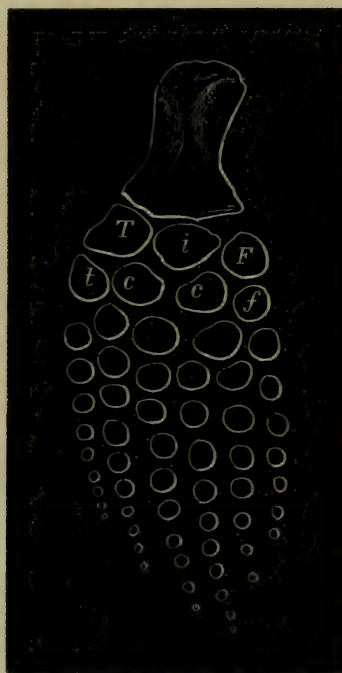
T, the tibia=66, tibia, Ow.; 67, the intermedium=fibula, Ow.; 67', the fibula=fabella, Ow.; t, os tibiale; c<sup>1</sup>, c<sup>2</sup>, ossa centralia.

itself; and the ossicle marked 67 in the same figure is not the fibula, as its number would imply, but it is the intermedium. In the diagram fig. 7 (copied from fig. 3 in pl. xli. vol. xxv. Quart. Journ. Geol. Soc. 1870), which represents the paddle of *Plesiosaurus Manseli*, the letter T marks the tibia (=66 Owen), i denotes the intermedium (=67 Owen), and F the fibula (=67' Owen). I imagine that the identity of these three elements in the epipodial segment of the above two paddles is unquestionable, and also that their identity with the three epipodial elements in the paddle of *Sauranodon* figured by O. C. Marsh is beyond doubt (fig. 9). I think also that the homology of the two laterally placed ossicles in the epipodium of *Sauranodon* with the two similarly situated ossicles in the epipodium of *Ichthyosaurus* (fig. 10) cannot be disputed. But these latter are by general consent the homologues of the tibia and fibula of higher vertebrates. It follows, therefore, that the lateral ossicles in the epipodium of *Pliosaurus portlandicus* (66, 67') and in that of *Plesiosaurus Manseli* (T, F) are also the tibia and fibula. Now the middle ossicle in the epipodium of *Sauranodon* has been identified by O. C. Marsh, rightly as I think, with the *intermedium*, the opinion at which I had myself arrived with respect to the corresponding element in *Plesiosaurus Manseli*, though noticing its agreement with the ossicle which in *Ichthyosaurus* is intercalated between the distal halves of the tibia and fibula. Here it has lost



the last touch of the femur or propodial element of the limb, and, thrust out of the epipodium, it appears henceforth to belong to the

Fig. 9.—*Hind limb of Sauranodon, Marsh.*



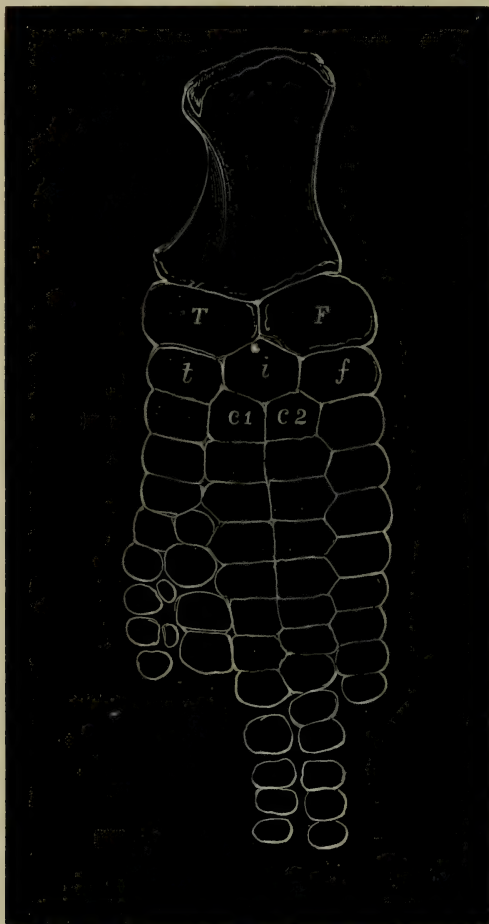
T, the tibia; i, the intermedium; F, the fibula; t, os tibiale; f, fibulare  
c, c, ossa centralia.

mesopodium, as O. C. Marsh has remarked in *Sauranodon*. From this arrangement to such a mesopodium (carpus, tarsus) as that of the living *Cryptobranchus japonicus* (fig. 13), or of the common land-Salamander (figs. 11, 12), is but a small step.

Another morphological question upon which the Enaliosaurian paddles throw light is the primitive duality or singleness of the os centrale of the carpus or tarsus (mesopodium), about which opinions differ; for in some extant Amphibia the carpus (tarsus) contains one os centrale, while in others two ossa centralia are present; and this difference has been occasionally observed in the right and left carpus of the same individual. Now in *Sauranodon* (fig. 9), *Ichthyosaurus* (fig. 10), *Pliosaurus portlandicus*, Owen (fig. 8), and, I believe, also in *Plesiosaurus Manseli*, the proximal row in the mesopodium (carpus or tarsus) comprises four ossicles, of which, since the two lateral ossicles must by their relations be the os tibiale, os fibulare (os radiale, os ulnare), the two middle cannot be other than two ossa

centralia, which manifestly favours the primitive duality of this mesopodial (carpal, tarsal) element.

Fig. 10.—*Hind limb of Ichthyosaurus.* (After Hawkins.)

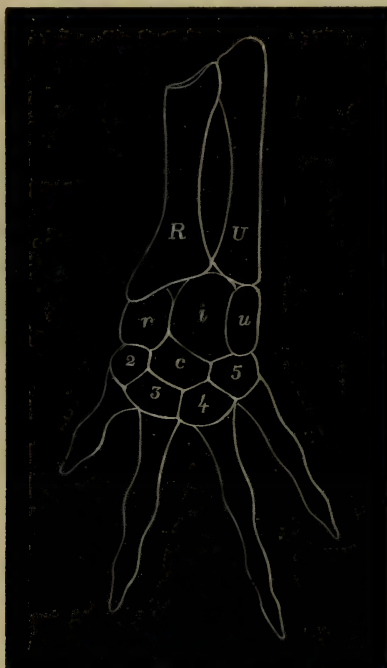


T, the tibia; F, the fibula; *t*, os tibiale; *f*, os fibulare; *i*, os intermedium; *c*<sup>1</sup>, *c*<sup>2</sup>, ossa centralia.

There remains for me to notice the scapula. In *Ichthyosaurus* (fig. 1) its form is well understood. In *Plesiosaurus* Prof. R. Owen, as has been already mentioned, believes that it has no dorsal extension answering to the blade in other Vertebrata; but he finds such an extension of the bone in *Pliosaurus*. I had thought that such dorsal extension of the scapula was recognizable in skeletons of

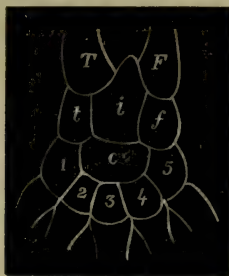
*Plesiosaurus* presented to the British Museum; it is certainly very obvious in the skeleton of *Plesiosaurus cliduchus* in the Wood-

Fig. 11.—*Forearm and Hand of Salamandra maculosa*. (After Hoffmann in Bronn's 'Thierreich.')



R, the radius; U, the ulna; u, the os ulnare; r, the os radiale; i, the os intermedium; c, the os centrale; 2-5, the distal carpalia.

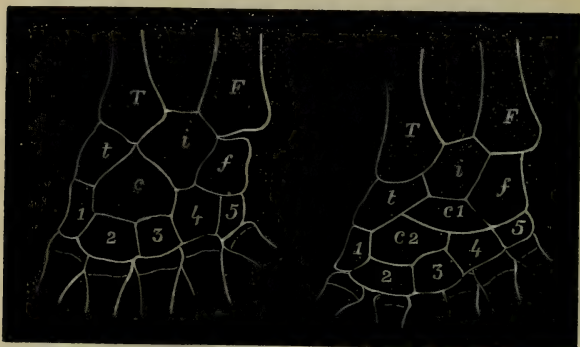
Fig. 12.—*Leg and Foot of Salamandra, sp.* (After Hoffmann in Bronn's 'Thierreich.')



T, the tibia; F, the fibula; t, the tibiale; f, the fibulare; i, the intermedium; c, the os centrale; 1-5, the distal carpalia.

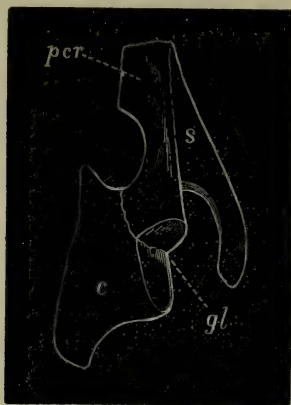
wardian Museum (fig. 14); there are indications of its presence in the skeleton of *Plesiosaurus Etheridgii* in the Museum in Jermyn

Fig. 13.—*Leg and Foot of Cryptobranchus japonicus*. (After Wiedersheim in Gegenbaur's *Morphol. Jahrb.* iii.)



T, the tibia; F, the fibula; *t*, os tibiale; *f*, os fibulare; *c*, *c* 1, *c* 2, ossa centralia; *i*, os intermedium; 1-5 distal carpalia.

Fig. 14.—*Plesiosaurus cliduchus*. (From a photograph of the fossil in the Woodwardian Museum.)



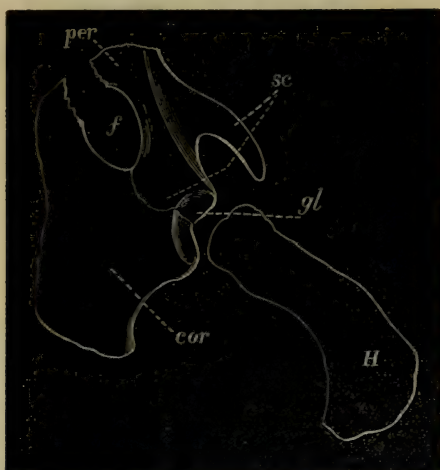
*s*, scapula; *c*, the coracoid; *per*, the præcoracoid; *gl*, the glenoid fossa.

Street; and it is, I venture to say, impossible to overlook it in the admirably executed cast of a skeleton of *Plesiosaurus dolichodeirus* which forms one of the treasures in our own Museum (fig. 15). This cast, with others, Mr. Dallas informs me, was presented to the Society by Baron Cuvier on the 3rd February, 1829; and these specimens are mentioned by the President, Dr. Fitton, in his anniversary address on the 20th of the same month in that year, as "doubly valuable on account of their connexion with his own [Cuvier's] publications." I



submit, then, that the evidence of a dorsal extension of the scapula in *Plesiosaurus* is irrefragable. With regard to its presence in *Pliosaurus*, whilst I do not see any reason to doubt it (for analogy

Fig. 15.—*Plesiosaurus dolichodeirus*. (From a cast in the Geological Society's Museum.)



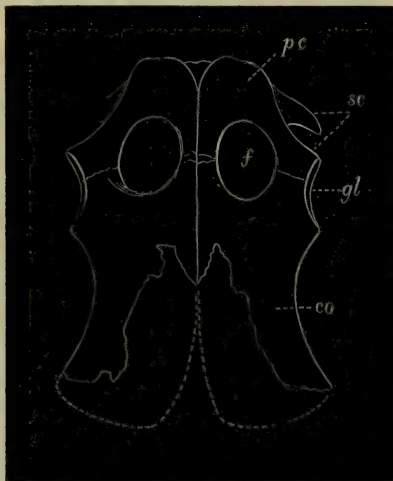
*per*, the praecoracoid; *sc*, the scapula; *cor*, coracoid; *f*, foramen  
H, the humerus; *gl*, the glenoid fossa.

would lead one to expect it), I find in the British Museum only two specimens bearing on the question, and cannot learn of the existence of others. They are a pair of scapulæ associated with a trunk-vertebra and ribs assigned to *Pliosaurus planus*, Owen, and the very fine, almost perfect, shoulder-girdle, a dissociated fossil, purchased some years ago, I think, of Mr. Charlesworth, and referred to *Pliosaurus*, sp. inc. (fig. 16). The generic identification of these two fossils with *Pliosaurus* being, as I submit, non-proven, they cannot afford decisive evidence of the form of the scapula in this genus. On the other hand there is unimpeachable evidence that Plesiosaurians of the Elasmosaurian pattern, as *Colymbosaurus*, long-necked and therefore certainly not Pliosaurian, had a scapula sending off "dorsad and laterad" such a blade or process as was ascribed by Prof. Owen to *Pliosaurus*, and represented by him in his figure of the "sterno-coraco-scapular frame," which it is believed was suggested by the fossil No. 46833 in the British Museum. With respect to *Ples. Manseli*, since its coracoids resemble those of No. 46833, analogy justifies the inference that there is a corresponding agreement of the scapulæ.

Another generic character of *Pliosaurus*, found by Prof. Owen in the junction of the anterior recurved part of the (praecoracoid) scapula (Ow.) with the narrow anterior præglenoid part of the coracoid, at the mesial and inner border of the coraco-scapular vacuity,

was given by Prof. Cope in 1870 as a character of his genus *Elasmosaurus*, a very long-necked Plesiosaurian, to which, as already

Fig. 16.—*Shoulder-girdle of Pliosaurus, Owen.*



*pc*, the præcoracoid; *co*, the coracoid; *sc*, the scapula; *gl*, the glenoid fossa; *f*, the coraco-scapular vacuity.

said, *Plesiosaurus Manseli*, *Ples. cliduchus*, and *Oolymbosaurus* seem nearly related. The present untrustworthiness of generic characters of *Pliosaurus* deduced from the propodial, epipodial, and mesopodial segments of the limbs has already been shown. These and similar defects in regard to the shoulder-girdle do not, however, necessarily annul the genus, which, in spite of them, may survive to afford another illustration of the Linnean aphorism, "Character non facit genus, sed genus dat character."

The remaining four reptilian papers referred to members of the subclass Dinosauria. Three of these were by Prof. H. G. Seeley. One was a description of a sacrum, represented chiefly by a cast in sandstone, remarkable for the large number (seven) of the vertebral centra composing it, and for the lateral compression and height of the neural canal. The same author, in another paper, brought under our notice some thoracic vertebræ from Wealden rocks, distinguished by the lateral compression of the centrum inferiorly, which suggested the name *Sphenospondylus*. It is a form of vertebra not uncommon at more than one horizon in the Wealden cliffs of the south coast of the Isle of Wight, from which I have myself dug out several, one of which was associated with an *Iguanodont* ischium. This and the close resemblance of their compressed figure to that of the centra of the same part of the vertebral column in *Iguanodon Prestwichii* led me to refer such vertebræ to a species of *Iguanodon*. The last two papers I shall notice are a description

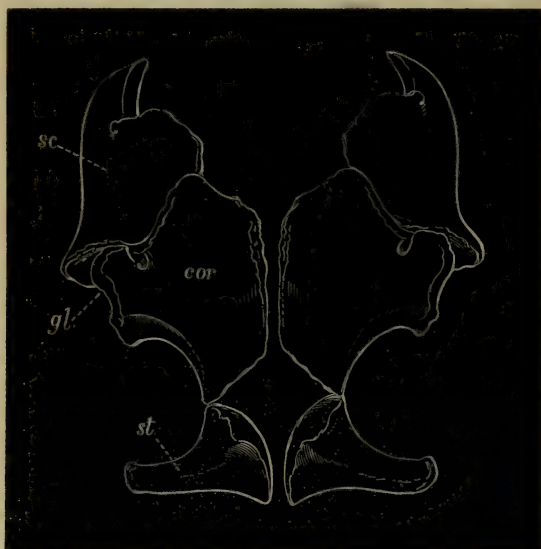
by Prof. H. G. Seeley of an extremely fine coracoid ascribed by him to the genus *Ornithopsis*, and one by myself describing an ischium and pubis referable to the same genus, which contains the largest and most singularly constructed of all our Dinosauria. These fossils confirm the close parallelism between some of our Wealden Dinosauria and certain North-American forms of Prof. O. C. Marsh's suborder Sauropoda, to which attention has been called by Prof. R. Owen, myself, and others. This resemblance will be yet more clearly shown, I believe, when the magnificent memoir on the North-American Dinosauria, illustrated by ninety 4to plates, upon which Prof. O. C. Marsh is now engaged, is published.

I cannot dismiss the Dinosauria without commending to your notice the excellent "Note première sur les Dinosauriens de Bernissart," par M. Dollo, Aide-Naturaliste au Musée Royal d'Histoire Naturelle de Belgique, extrait du Bulletin du Musée Royal, t. i. 1882, pl. ix. Here now are first depicted the shoulder- and hip-girdles with the fore and hind limbs of *Iguanodon Mantelli*, and also those of a bulkier species with which M. Dollo, with much probability, identifies my *I. Seelyi*. It was with no small pleasure that I saw reproduced in natural articulation the arrangement of the ventral bars of the hip-girdle, of which I have diagrammatically given a figure at p. 365 of vol. xxxii. of our Quarterly Journal for 1875.

M. Dollo, in this note, calls attention to the edentulousness of the præmaxilla in *Iguanodon*, which constitutes an important distinction from *Hypsilophodon*. He shows that the "radial spine" of Prof. Owen is the modified ungual phalanx of the thumb (as may, indeed, be seen in the figure in the fossil reptilia taken from Mr. Beccles's specimen). M. Dollo's figures demonstrate that the number of the phalanges in any toe of the pentadactyle fore foot does not exceed three, a frequent number in Amphibia, the dominant number in Chelonia, and that characteristic of the higher vertebrates, a point worth noticing. In a "Deuxième Note" which he most courteously sent me a few days since, M. Dollo proposes to make known the sternum, of which he writes, "je dirai d'abord que je ne connais aucun reptile vivant ou fossile possédant un appareil sternal qui puisse être mis en parallèle avec celui des Dinosauriens de Bernissart," a remark which will be echoed by every one who looks at the diagram made by Mr. W. R. Jones from M. Dollo's figure (fig. 17). Pending the confirmation of M. Dollo's restoration of the shoulder-girdle by other skeletons of *Iguanodon* in the Brussels collection yet unstripped of matrix, if I were disposed to speculate, taking as my guide the coracoids of *Sphenodon* or *Chamaeleon*, which in their simplicity most nearly resemble those of *Iguanodon*, I should put a crescentic lip of cartilage on the mesial border of the latter (representing præ- and epicoracoid), intercalate between them a rhomboidal sternum, and attach to the posterior margins of this some of the foremost ribs (fig. 18); that M. Dollo has rightly interpreted the bones marked S. in his figure of the sternum, I confess to feeling some doubt; they are the bones which Prof. O. C. Marsh considered clavicles, but which I myself had thought to resemble

the dilated riblets at the root of the neck in living lizards, immediately preceding those which join the breast-bone, more nearly than any other skeletal elements with which I am acquainted; but the absence of any indication of bifurcation made me hesitate to consider them such, because all the cervical and the foremost thoracic ribs in *Iguanodon* have a forked vertebral end. If sternal, I should

Fig. 17.—*Shoulder-girdle of Iguanodon.* (From M. Dollo's figure.)



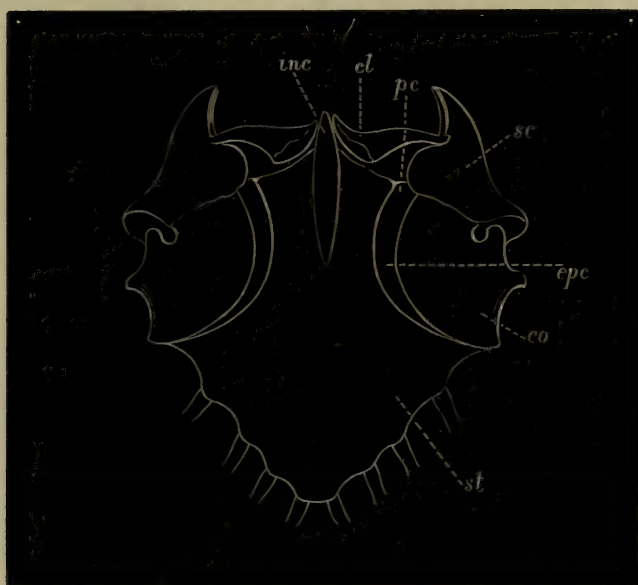
sc, the scapula; cor, the coracoid; st, the sternum; gl, the glenoid fossa.

invert the base, and directing the narrow end downwards, regard them as the homologues of xiphisternals only; but to this hypothesis, not less than to their supposed homology with the paired sternal plates of *Brontosaurus*, there seem to me to be strong objections, notably the absence of marks of costal attachments; so that, upon a review of all the circumstances, I think the balance of probabilities inclines towards Prof. O. C. Marsh's opinion that they are clavicles. To the objection that had such a rhomboidal sternum as I have imagined actually existed it must have been preserved, I would reply that this presupposes that it must have been an osseous plate; but the analogy of Crocodilia shows that it might have been cartilaginous, and have perished with the rotting of the carcass, the episternum alone remaining; and this is favoured by M. Dollo's discovering between the coracoids and his xiphisternals (?) "une pièce osseuse, fusiforme et légèrement bombée sur sa face centrale," which he is himself disposed to regard as episternal; for one can hardly suppose it probable that the bony sternum perished while the episternum was preserved.



Rich as are the spoils acquired at Bernissart, they are much exceeded by the vast quantities of vertebrate remains which for several years past have been obtained in the United States of America from

Fig. 18.—*Shoulder-girdle of Iguanodon.*



*inc*, the interclavicle; *cl*, the clavicle; *sc*, the scapula; *epc*, the epicoracoid.

Jurassic and newer rocks. Dr. Hayden wrote to me in December that Prof. Cope had in the press an important volume illustrated by 200 plates, belonging to his quarto series, which he hoped would appear in the spring. Prof. O. C. Marsh's admirable monograph "On the Toothed Birds" witnesses to the abundance and completeness of preservation of the ornithic remains. The lithographic illustration of this memoir cannot, I think, be excelled. The same exquisite rendering is apparent in his figure of *Ramphorhynchus phyllurus*, a Solenhofen Pterodactyle, in which the artist has succeeded wonderfully in reproducing the delicate marking and folds of the wing-membranes. In the article on "The Wings of Pterodactyles," which this figure illustrates, Prof. Marsh mentions that the collections of Yale College contain 600 specimens of Cretaceous Pterodactyles, nearly all of gigantic size, having a spread of wing from 15 to 20 feet, toothless, and therefore belonging to the order Pteranodonta, and exhibiting the peculiarities of an anchylosis of several of the thoracic vertebrae and synostosis of their spinous processes, to which latter the suprascapulae are firmly joined, thus repeating in the shoulder-girdle the sacrum and sacro-iliac union

of the hip-girdle. Anchylosis of a variable number of the trunk-vertebræ is a well-known occurrence in birds; but in them the suprascapulæ are devoid of fixed connexion with the vertebral column. The only vertebrates in which I know of a similar arrangement to that observed in *Pteranodon* are very far below the latter in the vertebrate scale. I refer to Skates, in which the vertebral spinous processes are wedged in between the suprascapulæ, which are firmly connected with them by fibrous ligaments.

I cannot dismiss the Pterosauria without mentioning Prof. Karl Zittel's valuable memoir "Ueber Flugsaurier aus dem lithographischen Schiefer Bayerns," published in the 'Paleontographica' in October 1882. It contains an excellent description of the wing-membrane of *Rhamphorhynchus Gemmingi*, H. v. Meyer, from an excellently preserved specimen found near Eichstadt and acquired by the Munich Museum. The accompanying photograph shows the delicate wrinkling of the membrane, and the same long, elegantly tapering form of wing displayed by Prof. Marsh's specimen. Prof. Zittel confirms Marsh's determination of the pteroid bone as the metacarpal of the pollex, and corroborates his view of the wing-finger being the fifth.

A beautifully perfect skull of this same species of *Pterodactyle* shows that the sclerotic coat of the eyeball had a circle of bony plates; and consequently this feature loses its value as a distinction between *Rhamphorhynchus* and *Pterodactylus*, of which latter genus H. v. Meyer had thought it characteristic. A third specimen shows the number of sacral vertebræ to be four, and not three, as had been previously supposed; that the ilium had a long and expanded ant-acetabular and a short and slender postacetabular process; the pubis a narrow, angularly bent bar, directed forwards and inwards, met its fellow ventrally in a median symphysis; whilst the ischia are broad, vertical, slightly converging plates which do not meet one another, but leave the pelvic outlet widely open below. The avian similarity of the ilia and ischia should be noticed.

Leaving these dry bones for subjects of wider interest, the recently published 'Compte Rendu' of the Second International Congress held at Bologna is too important to pass unnoticed. The excellence of the type, the fineness of the paper, the whole style and appearance of the volume do great credit to the Imprimerie Fava et Guragnani, from whose press it issued. Probably the most valuable scientific work of the Congress were the deliberations upon the "Rapports des Commissions Internationales pour l'Unification de la Nomenclature Géologique, et pour la question des Règles à suivre pour établir la Nomenclature des Espèces." The decisions of so important a body on subjects of such moment deserve our earnest attention, and it would be well for every one of our Fellows to make himself familiar with them. Of the advantages likely to accrue from such international uniformity of stratigraphical terms it is impossible to entertain any doubt; they are indeed so great that to not a few geologists they would appear sufficient to compensate for temporary inconveniences such as those incidental to the suppression of

familiar names, or even the introduction of new ones. At present, even within the limits of our country and its dependencies, stratigraphical and chronological terms do not bear invariably precisely the same meaning in the writings of different authors, and similar differences may be noticed in the colouring and graphic marking of maps.

This indubitably tends to create confusions and misapprehensions, real hindrances to the acquisition and spread of geological knowledge, which all must desire to see removed. The projected execution at Berlin of a geological map of Europe, under the direction of a Committee of the Congress, will afford to all an opportunity of seeing the proposed method of colouring and the graphic signs.

The decisions of the Congress with respect to palæontological nomenclature have a peculiar force at the present time, when the multiplication of genera and species by the discovery of distinctly new forms, or the renaming of old ones (a not unfrequent event of late), proceeds at a prodigious rate. The truth of the following extract from a letter addressed by M. Alph. de Candolle to M. Capellini, the President of the Congress, will be apparent to every one; he writes:—"S'il y a quelque chose de vague et de contestable dans les sciences naturelles, c'est la distinction des espèces en paléontologie. On ne voit jamais tous les caractères qu'il faudrait connaître pour les distinguer;" and he illustrates this by reference to the varying forms of the leaves of plants, remarking that one single stem of *Eucalyptus* would by its leaves supply five or six such species as are admitted into palæontology, and one of *Broussonnetia* would yield from ten to fifteen.

It will be within the recollection of some present that in the early part of last session Mr. J. S. Gardner, in the discussion which followed the reading of his paper "On the Geology of Madeira," drew attention to the confusion arising from this cause, and instanced the many variations of the leaf-form in *Rubus*.

I may not hold palæontologists wholly blameless in respect of the reproach conveyed in M. de Candolle's letter. One taxonomy should apply to the dead and the living, since each of these are but the earlier and the later links in our ever onward-moving series of beings. Any such distinction as is implied in the popular idea of a palæontologist as a person wholly concerned with extinct and a zoologist as wholly busied with living forms is to be deprecated. The past and the present are complementary, they are mutually illustrative. It is not possible to understand extinct forms without an acquaintance with those now living; and living forms are simply unintelligible, so far as relates to a right comprehension of them, without an acquaintance with the extinct.

In conclusion, one very important event which took place during the meeting of the Congress must be mentioned; it is the founding of the "Geological Society of Italy." Let us wish it God-speed, and cherish the hope that the circumstances of its birth may prove a happy augury of its future prosperity.



February 21, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Rev. John Birks, 4 Park Terrace, Taunton; Capt. James Scott Black, 4 Upper Brook Street, Grosvenor Square, W.; John Bradford, Esq., East Acton, W.; Thomas Alexis Dash, Esq., M. Inst. C.E., The Hollies, Feltham, Middlesex; Henry Lewis, Esq., Annesley, Nottingham; and Thomas Morris, Esq., Bridge House, Warrington, were elected Fellows of the Society.

A set of Thirty Microscopic Slides, showing the condition of gold and sands found with Placer Gold in California, were presented to the Museum by H. G. Hanks, Esq., State Mineralogist, San Francisco.

The Secretary read the translation of a letter from Prof. H. R. Göppert, F.M.G.S., relating to the first volume of his work on 'Vegetable Remains in Amber,' of which the first completed copy had been sent by him to the Society's Library in acknowledgment of the award to him of the Murchison Medal. The letter is as follows:—

HONOURED MR. PRESIDENT,—

I have just received from Danzig the information that my work upon Amber, which has been printed there, is ready for issue. At my special desire at least one copy of it has been got ready, which, although I have not seen it, I have the honour to send to your honourable Society. It is the first Section upon the Coniferæ of Amber, a work which called for much preliminary labour, and the production of which has consequently been delayed until the late evening of my life. Amber is indisputably the richest of all fossils in marvels, seeing that it alone, by its vegetable and animal enclosures, has preserved the extremely rich flora and fauna, and furnished us with an insight into that period of which no other can boast. In this transparent grave of a flora long since passed away, remains of plants have been found by me which are regarded as characteristic plants of every Miocene flora, and thus indicate their position with certainty. In the present work these are Cupressineæ: and among them such as furnish proofs of the infinite duration of a species, as *Thuja occidentalis*, *Riota orientalis*, *Cupressus sempervirens*, *Taxodium*, &c. This will be still more recognizable in the inclusions of cryptogamic cellular plants, especially the Fungi. Some 23 species of all the chief groups are present—even an *Isaria* with *Astrota lagmus* as evidences of alternation of generations, *Ascomycetes*, *Peziza*, *Clavaria*, *Boletus*, which, like the species of Lichens, cannot be distinguished from those of the present day—and, with the numerous mosses present, will complete



the whole Tertiary flora, if we wish to obtain the general picture of a flora. These will constitute the following volume.

In the elaboration and the discovery of the materials for this next volume, Professor A. Menge, who died in Danzig in January 1880, has an important share. The collection of inclusions in Amber, his work, is now in the possession of the Naturforschende Gesellschaft zu Danzig, as an inestimable treasure. But all that relates to the Amber tree, some 1000 hand specimens and preparations, belongs to my collection. The figures on Taf. iv.–viii. also show the types of the fossil Coniferæ, which may serve for the determination of fossil Coniferæ in general and of the remains of wood enclosed in Amber. Among them the type of the *Araucaria* (our *Araucarites*) merits special mention, in remembrance of its introduction by Witham into his classical memoir 'The Internal Structure of Fossil Vegetals' (Edinburgh, 1833), which will always claim an honourable place in the history of phytopalæontology.

In conclusion, I introduce in my work an attempt to explain the enigmatical fossilization of Amber, and the disappearance of the trunks furnishing the Amber, which only remain to us in a few fragments of 2–3 inches long in my possession.

(Signed) Dr. HEINRICH ROBERT GÖPPERT.

The following communications were read:—

1. "On the Relation of the so-called 'Northampton Sand' of North Oxfordshire to the Clypeus-Grit." By Edwin A. Walford, Esq., F.G.S.

2. "Results of Observations in 1882 on the Positions of Boulders relatively to the Underlying and Surrounding Ground, in North Wales and North-west Yorkshire; with Remarks on the Evidence they furnish of the Recency of the Close of the Glacial Period." By D. Mackintosh, Esq., F.G.S.

[Abstract.]

The author began by showing how boulders may be regarded as natural time-measurers by their protecting the rock-surface underneath from the action of rain, which, around the boulders, denudes the surface, especially on the leeward and windward sides, where hollows resulting from pluvio-torrential action may generally be seen. He then described and explained the origin of the different forms of *supports* under boulders, which graduate from flat surfaces to *pedestals* of various forms, which he divided into *appropriated* (or preexisting), and those *acquired* through the boulders protecting the underlying rock from denudation. The author then described the positions of boulders on the high and uninhabited Eglwyseg limestone plateau near Llangollen, where it is certain they had never been disturbed by man. There he found that the average vertical extent of denudation by pluvial action around the boulders, since their arrival, was not more than six inches. After

endeavouring to account for the fractured and crushed condition of the rocks under these boulders by precipitation from floating ice, he gave an account of his discoveries on the high limestone plateau north-east of Clapham (Yorkshire), where there is a "ghastly array" of many hundreds of large Silurian grit and slate boulders, nearly black in colour. From many facts and considerations the author endeavoured to show that most of the pedestals of these boulders must have existed *before* the arrival of the boulders, while the pedestals *acquired* through the boulders protecting the underlying rock from denudation were generally imperfectly formed. On the Clapham plateau he found that the *average* vertical extent of denudation around the boulders with acquired pedestals was not more than on the Eglwyseg plateau, or about six inches. In the case of boulders which were not well adapted to concentrate rain-water, the extent of lowering of the surrounding rock-surface was often inappreciable; and this accounted for the continuous extension of flat limestone rock-surfaces under some of the boulders. The author then described what he had found to be *preglacial* as well as postglacial rain-grooves on limestone rock-surfaces, near Minera and on Halkin mountain (North Wales), where he found the average depth of those of the grooves which were probably postglacial to be about six inches. In conclusion the author entered into a consideration of the time which has elapsed since the close of the glacial period, and stated the main results of his observations as follows:—

1. That the average *vertical extent* of the denudation of limestone rocks around boulders has not been more than six inches.
2. That the average *rate* of the denudation has not been less than one inch in a thousand years.
3. That a period of not more than six thousand years has elapsed since the boulders were left in their present positions by land-ice, floating ice, or both.

#### DISCUSSION.

Prof. HUGHES bore testimony to the value of the labours of Mr. Mackintosh in recording the character and manner of occurrence of boulders scattered over Wales and the North of England. He pointed out, however, that the calculations of the rate of waste made by the authors quoted was founded upon observations over a very large area, where the hard and soft rocks compensated for one another, and an average was obtained, but that this rate could not be taken as that of any one rock-surface such as referred to by Mr. Mackintosh. He had himself, in 1867 \*, described the Norber boulders, and proposed the question, "Assuming the average periodic rainfall to have been constant, or any rate to be determinable, and the quantity of limestone removed by a given quantity of rain-water to be known, to find how many years have elapsed since this limestone was exposed to subaerial denudation." But the rainfall

\* Geol. and Polytechnic Soc. West Riding, Yorkshire, July 1867, p. 11.

cannot be assumed to have been constant; and though it is known that *pure* water will take up 2 grains per gallon of carbonate of lime, the rain-water that acted on the limestone was not pure, but had obtained from various sources a considerable but variable quantity of carbonic acid, which would enable it to remove the limestone far more rapidly. Moreover it was not at all clear that the boulders had been left on a clean surface of limestone, but many of them probably were left there when the Boulder-clay in which they had been imbedded was washed away by streams of water not strong enough to carry the boulders too. He thought that the breaking-down of parts of the pedestal was due to the weight of the boulder when denudation along joints and furrows had isolated and undermined small portions, and that if they had been dropped through water the velocity would have been checked, or if, as was more probable, left by a glacier, they would not have been dropped on to the bare rock at all; and he gave the example of boulders hurled by a torrent against the wall of Gaping Gill, and only bruising the surface of the rock, but not breaking it up.

Mr. TIDDEMAN agreed in the main with Prof. Hughes as to the Norber boulders. If the rate of waste of limestone could be ascertained, that would only give us a minimum of the time elapsed. But the hypothesis that the boulders had been dropped on pre-existing pinnacles was highly improbable. The arrangement of the boulders on a plateau of limestone with scratches beneath them, and scratches on the parent rock to the north at a lower level, though higher up the valley, these scratches being in the same straight line, showed distinctly that the agent was land-ice.

Dr. HICKS thought Mr. Mackintosh had failed to prove his theory. Most of these areas must have been covered by Till. He showed by a section how the boulders were imbedded in the Till.

Prof. BONNEY said there were many theoretical difficulties in Mr. Mackintosh's supposition, although it was remarkable how little change had taken place in some regions since the disappearance of the ice. History or tradition reached back for at least half the period of 6000 years, and there was no hint of a refrigeration of climate; 10,500 years was required for the maximum of cold, if we were to assign a lowering of temperature to precession; while, if we consult the tables of the values of the eccentricity of the earth's orbit, we find the first high eccentricity was 100,000 years ago, so that 6000 years from the present time the change due to this would hardly be appreciable.

3. "Notes on the Corals and Bryozoans of the Wenlock Shales (Mr. Maw's Washings)." By G. R. Vine, Esq. Communicated by Prof. P. Martin Duncan, M.B., F.R.S., V.P.G.S.

[Abstract.]

The author briefly discussed the views of different writers upon the systematic position of the genera *Chaetetes*, *Monticulipora*, and their allies, and also of the forms referred to the Polyzoa, and gave

a list of 39 species and varieties of Corals and Polyzoa obtained by him from Mr. Maw's washings of deposits belonging to the Wenlock series in Shropshire. These forms were referred by him to the genera *Dekayia*, *Monticulipora*, *Callopora*, *Heliolites*, *Thecia*, *Favosites*, *Syringopora*, *Halysites*, *Cænites*, *Cyathophyllum*, *Lindstroemia*, *Cladopora*, *Leioclema*, *Ceripora*, and *Ceramopora*. New species are *Leioclema granatum* and *pulchellum*.

Specimens were exhibited by Messrs. Walford and Vine, in illustration of their papers.

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March 7, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Thomas Gustav Hawley, Esq., Park Hill, Kenilworth; Richard Lydekker, Esq., B.A., The Lodge, Harpenden, Herts; and J. O'Donoghue, Esq., 1 Cambridge Villas, Cambridge Gardens, Notting Hill, W., were elected Fellows, and M. F. L. Cornet, of Mons, a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

Specimens of Fossil Plants from the Coal-measures of Cape Breton, Nova Scotia, were presented to the Museum by C. Barrington Brown, Esq., F.G.S.

The following communications were read:—

1. "On Gray and Milne's Seismographic Apparatus." By Thomas Gray, Esq., B.Sc., F.R.S.E. Communicated by the President.

2. "Notes on some Fossils, chiefly Mollusca, from the Inferior Oolite." By the Rev. G. F. Whidborne, M.A., F.G.S.

3. "On some Fossil Sponges from the Inferior Oolite." By Prof. W. J. Sollas, M.A., F.G.S.

4. "On the Dinosaurs from the Maastricht Beds." By Prof. H. G. Seeley, F.R.S., F.G.S.

The following objects were exhibited:—

The Gray and Milne Seismographic Apparatus, exhibited by T. Gray, Esq.

Specimens from the Inferior Oolite, exhibited by the Rev. G. F. Whidborne, M.A., F.G.S., in illustration of his paper.



March 21, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Charles Albert Barber, Esq., 5 Furnival's Inn, Holborn, E.C., and Bristol House, Brighton, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communication was read:—

“On the Supposed Pre-Cambrian Rocks of St. David's.” By Archibald Geikie, Esq., LL.D., F.R.S. (Part I.)

Rocks and microscopic sections were exhibited by A. Geikie, Esq., in illustration of his paper.

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April 11, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Robert Kidston, Esq., 24 Victoria Place, Stirling; and Prof. Henry Shaler Williams, Ph.D. (Yale), Cornell University, Ithaca, N.Y., U.S.A., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following presents were made to the Museum:—A collection of Rocks and Fossils from Japan, presented by Prof. John Morris, M.A., F.G.S., and Rock specimens from Williams Cañon, Colorado, presented by H. Bauerman, Esq., F.G.S.

The following communication was read:—

“On the Supposed Pre-Cambrian Rocks of St. David's.” By Archibald Geikie, Esq., F.R.S., F.G.S. (Part II.)

The following specimens were exhibited:—

Rocks and Rock-sections, exhibited by A. Geikie, Esq., in illustration of his paper.

Rocks from St. David's, exhibited by Dr. H. Hicks.

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April 25, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Rev. William Franklen Evans, M.A., Felstead School, Essex; Ernest Hall Hedley, Esq., Gellygron, Pontardawe, near Swansea; and Henry James Plowright, Esq., Brampton, Chesterfield, were elected Fellows, and Dr. J. S. Newberry, of New York, a Foreign Member of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "On the Skull of *Megalosaurus*." By Prof. R. Owen, C.B., F.R.S., F.G.S.

2. "Notes on the Bagshot Sands." By H. W. Monckton, Esq., F.G.S.

3. "Additional Note on Boulders of Hornblende Picrite near the Western Coast of Anglesey." By Prof. T. G. Bonney, M.A., F.R.S., Sec. G.S.

The following specimens were exhibited :—

Fossils from the Bagshot Sands, exhibited by H. W. Monckton, Esq., in illustration of his paper.

Rocks and microscopic sections, exhibited by Prof. T. G. Bonney, in illustration of his paper.

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May 9, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Rev. William Spiers, M.A., Lily Bank, Chorlton-cum-Hardy, Manchester; and H. A. Williams, Esq., 91 Pembroke Road, Clifton, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. "The Age of the newer Gneissic Rocks of the Northern Highlands." By C. Callaway, Esq., D.Sc., F.G.S. With Notes on the Lithology of the Specimens collected, by Prof. T. G. Bonney, M.A., F.R.S., Sec. G.S.

2. "On a group of Minerals from Lilleshall, Salop." By C. J. Woodward, Esq., B.Sc., F.G.S.

3. "Fossil Chilostomatous Bryozoa from Muddy Creek, Victoria." By A. W. Waters, Esq., F.G.S.

The following were exhibited :—

Microscopic Preparations of Algoid Bodies found in Russian Coal, exhibited by E. T. Newton, Esq., F.G.S., on behalf of Dr. Reinsch.

Specimens of Shells found in Drift at a Depth of 21 feet, at Whitchurch, Shropshire, exhibited by the Rev. T. W. Norwood, F.G.S.

Rock-specimens, exhibited by Dr. Callaway, in illustration of his paper.

Minerals, exhibited by C. J. Woodward, Esq., in illustration of his paper.

May 23, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Ernest Le Neve Foster, Esq., Georgetown, Colorado, U.S.A., and Richard Bullen Newton, Esq., Melrose Villa, Applegarth Road, West Kensington, W., were elected Fellows of the Society.

The List of Donations to the Library was read.

A specimen of a waterworn pebble of Galena from an alluvial deposit of lead-ore, Minera, Wrexham, was presented to the Museum by Dr. C. Le Neve Foster, F.G.S.

The following communications were read :—

1. "On the Basalt-glass (Tachylyte) of the Western Isles of Scotland." By Prof. J. W. Judd, F.R.S., Sec. G.S., and G. A. J. Cole, Esq., F.G.S.

2. "On a Section recently exposed in Baron Hill Park, near Beaumaris." By Prof. T. G. Bonney, M.A., F.R.S., Sec. G.S.

3. "On the Rocks between the Quartz-felsite and the Cambrian Series in the neighbourhood of Bangor." By Prof. T. G. Bonney, M.A., F.R.S., Sec. G.S.

The following were exhibited :—

Rock-specimens and microscopic sections, exhibited by Prof. J. W. Judd and G. A. J. Cole, Esq., in illustration of their paper.

Rock-specimens, exhibited by Prof. T. G. Bonney, in illustration of his papers.

Specimen of rock from Elbrouz, Asia Minor, at an elevation of about 17,500 feet, exhibited by Prof. T. G. Bonney.

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June 6, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

George Paul, Esq., Moortown, near Leeds, was elected a Fellow of the Society.

The following names of Fellows of the Society were read out for the first time in conformity with the Bye-Laws, Sec. VI. B. Art. 6, in consequence of the non-payment of the arrears of their contributions:—Rev. J. Crompton; J. Derrington, Esq.; Rev. J. T. C. Gullon; J. Harte, Esq.; D. R. Irvine, Esq.; T. R. Mellor, Esq.; R. Plant, Esq.; L. Rhys, Esq.; S. R. Smyth, Esq.; and Dr. E. H. W. Swete.

The List of Donations to the Library was read.

The following communications were read:—

1. "The Estuaries of the Severn and its Tributaries, an inquiry into the Nature and Origin of their Tidal Sediment and Alluvial Flats." By Prof. W. J. Sollas, M.A., F.R.S.E., F.G.S.

2. "Notes on a Collection of Fossils and Rock-specimens from West Australia, north of the Gascoyne River." By W. H. Hudleston, Esq., M.A., F.L.S., F.G.S.

3. "Notes on the Geology of the Troad." By J. S. Diller, Esq. Communicated by W. Topley, Esq., F.G.S.

The following objects were exhibited:—

Specimens, exhibited by Prof. W. J. Sollas and W. H. Hudleston, Esq., in illustration of their papers; and

Photographs of a fossil Saurian skeleton from the Upper Lias of Sedbury Cliff in Gloucestershire, exhibited by John Yeats, Esq.

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June 20, 1883.

J. W. HULKE, Esq., F.R.S., President, in the Chair.

Henry Yorke Lyell Brown, Esq., Director of the Geological Survey of South Australia, Adelaide; Edward St. F. Moore, Esq., Lieut. 4th Batt. Northamptonshire Regt., Woodbridge, Suffolk; John Henry Nichols, Esq., Sandfield Hall, Newton-le-Willows; and Henry Parker, Esq., Irrigation Officer, Public Works Department, Ceylon, were elected Fellows, and Baron F. von Richthofen, of Berlin, a Foreign Correspondent of the Society.

The following names of Fellows of the Society were read out for the second time in conformity with the Bye-Laws, Sec. VI. B. Art. 6, in consequence of the non-payment of the arrears of their contributions:—Rev. J. Crompton; J. Dorrington, Esq.; Rev. J. T. C. Gullon; J. Harte, Esq.; D. R. Irvine, Esq.; T. R. Mellor, Esq.; R. Plant, Esq.; L. Rhys, Esq.; S. R. Smyth, Esq.; and Dr. E. H. W. Swete.

The List of Donations to the Library was read.

The following communications were read:—

1. "On the Discovery of *Ovibos moschatus* in the Forest-bed, and its Range in Space and Time." By Prof. W. Boyd Dawkins, M.A., F.R.S., F.G.S.

2. "On the Relative Age of some Valleys in Lincolnshire." By A. J. Jukes-Browne, Esq., B.A., F.G.S.

3. "On the Section at Hordwell Cliffs, from the top of the Lower Headdon to the base of the Upper Bagshot Sands." By the late E. B. Tawney, Esq., M.A., F.G.S., and H. Keeping, Esq., of the Woodwardian Museum. Communicated by the Rev. Osmond Fisher, M.A., F.G.S.

4. "On some New or imperfectly known Madreporaria from the Coral Rag and Portland Oolite of the Counties of Wilts, Oxford, Cambridge, and York." By R. F. Tomes, Esq., F.G.S.

5. "The Geology of Monte Somma and Vesuvius, being a Study in Vulcanology." By H. J. Johnston-Lavis, Esq., F.G.S.

6. "Note on 'Cone-in-Cone' Structure." By John Young, Esq., F.G.S.

[Abstract.]

This note was written with the object of calling the attention of the Geological Society to some very fine and remarkably interesting examples of "Cone-in-Cone" structure.

The author, after referring to the views of previous writers on the origin of this structure, proceeded to describe the interesting examples of it which occur in the coalfields of Ayrshire and Renfrewshire. He pointed out that the structure is generally exhibited in bands overlying beds of fossils.

7. "A Geological Sketch of Quidong, Manaro, Australia." By Alfred Morris, Esq., C.E., F.G.S.

[Abstract.]

This district is situated about 250 miles S.S.E. from Sydney. The cliffs about the Bombala river are about 100 to 120 feet high, and formed of very dark limestone, crowded with fossils, chiefly *Pentamerus*. In the author's opinion there has been great disturbance in this region, resulting in a complete change in the course of the river Bombala and a displacement of the shale. A mass of ferruginous sandstone has also been upheaved. This, as well as the other rocks in the neighbourhood, contain Upper Silurian fossils. It appears to have been altered by heat. Pockets of galena and copper are occasionally found in the district, and there is a vein of hæmatite. Clay-slates occur as well as the above rocks, the cleavage being generally vertical or nearly so.

The following specimens were exhibited:—

Specimen of the skull of *Ovibos moschatus*, exhibited by Prof. Boyd Dawkins, in illustration of his paper.

Rock-specimens, exhibited by H. J. Johnston-Lavis, Esq., in illustration of his paper.

Specimens of "Cone-in-Cone" Structure, exhibited by John Young, Esq., in illustration of his paper.

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# ADDITIONS

TO THE

LIBRARY AND MUSEUM OF THE GEOLOGICAL SOCIETY.

SESSION 1882-83.

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## I. ADDITIONS TO THE LIBRARY.

### 1. PERIODICALS AND PUBLICATIONS OF LEARNED SOCIETIES.

*Presented by the respective Societies and Editors, if not otherwise stated.*

Academy, The. Nos. 529-556. 1882.

——. Nos. 557-580. 1883.

Adelaide. Royal Agricultural and Horticultural Society of South Australia. Proceedings for the year ending March 31, 1881. 1881.

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——. Royal Society of South Australia. Transactions and Proceedings and Report. Vol. v. 1882.

R. Tate. Notes on the Tertiary Strata beneath Adelaide, 40.—R. Tate. Diagnoses of new Species of Miocene Fossils from South Australia, 44.—G. Scouler. The Geology of the Neighbourhood of Gawler, 57.—G. Scouler. Notes relating to the Geology between the Burra and Farina, 72.—R. Tate. Report on Minerals received from Mr. J. Chandler, 97.—R. Tate. Plant-bearing Beds between Lake Frome and the Barrier Ranges, 98.—J. A. Niemann. Section of Strata traversed by Boring at Wirrialpa Station, Frome Downs, about twelve miles south-east of Lake Frome, 99.

Analyst, The. Vol. vii. Nos. 76-81. 1882.

A. Hehner. New Analysis of the Sandrock (I. W.) Mineral Water, 109.

——. Vol. viii. Nos. 82-87. 1883.

Annals and Magazine of Natural History. Ser. 5. Vol. x. Nos. 55-60. 1882. *Purchased.*

G. J. Hinde. Notes on Fossil Calcispongiæ, with Descriptions of new Species, 185.—T. Rupert Jones. Notes on the Palæozoic Bivalved Entomostraca. No. XV. A Carboniferous *Primitia* from South Devon, 358.

Annals and Magazine of Natural History. Ser. 5. Vol. xi. Nos. 61-66. 1883. *Purchased.*

T. Fuchs. What is to be understood by the Term "Deep-sea Fauna" and by what Physical Conditions is its Occurrence governed?, 1.—C. Brongniart. A new Fossil Orthopterous Insect from the Coal-measures of Commentry, Allier, 71.—R. Etheridge, Jun., and P. H. Carpenter. Further Remarks on the Morphology of the Blastoidea, with Descriptions of a new British Carboniferous Genus and some new Devonian Species from Spain, 225.—R. Häusler. On the Jurassic Varieties of *Thurammina papillata*, Brady, 262.—R. Kidston. On the Affinities of the Genus *Pothocites*, Paterson, with the Description of a Specimen from Glen-cartholm, Eskdale, 297.—P. H. Carpenter. On the Supposed Absence of Basals in the Eugeniocrinidæ and in certain other Neocrinoids, 327.—Munier-Chalmas and Schlumberger. New Observations on the Dimorphism of the Foraminifera, 336.

Army Medical Department. Report for the year 1880. Vol. xxii. 1882.

Art-Union of London. Report of the Council for the year 1882. 1882.

Athenæum (Journal). Nos. 2852-2879. 1882.

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——. Parts 654-660. 1882.

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Ballaarat School of Mines. Annual Report, 1882. 1883.

F. M. Krause. Notes on the Geology of Lal Lal, 51.

Barnsley. Midland Institute of Mining, Civil, and Mechanical Engineers. Transactions. Vol. viii. Parts 60-65. 1882 & 1883.

Barrow Naturalists' Field Club. Transactions. Vol. iii. (1878-79). 1879. *Presented by W. Whitaker, Esq., F.G.S.*

E. Richards. Silica, 51.—W. Kendall. Mineralogy at the Paris Exhibition, 94.

Basel. Naturforschende Gesellschaft. Verhandlungen. 7 Theil, Heft i. 1882.

L. Rütimeyer. Studien zu der Geschichte der Hirschfamilie, 3.—P. Merian. Ueber einige Petrefakten von Melbourne (Australia), 183.—P. Merian. Ueber die angeblichen australischen tertiären Belemniten, 184.

——. Schweizerische paläontologische Gesellschaft. Abhandlungen. Vol. ix. 1882. *Purchased.*

A. Portis. Les Chéloniens de la molasse vaudoise.—P. de Loriol. Etudes sur la faune du Gault de Cosne.

Bath Natural-History and Antiquarian Field Club. Proceedings. Vol. v. No. 2. 1883.

J. McMurtrie. Notes on Autumn Excursions on the Mendips, 98.



Belfast Natural-History and Philosophical Society. Proceedings for the Session 1881–82. 1882.

J. J. Murphy. The Rainy or Post-Glacial Period, 54.—E. A. Letts. The Diamond, 58.—R. O. Cunningham. Corals and Coral Islands, 67.

Belfast Naturalists' Field Club. Annual Report and Proceedings. Ser. 2. Vol. ii. Part 1. 1882.

F. W. Lockwood. Glacial Notes amongst the English Lakes, 62.—J. Wright. Sponge-remains from the Carboniferous Limestone of Ben Bulbin, co. Sligo, Appendix, 189.

———. ———. ———. Vol. ii. Part 2. 1883.

Berlin. Deutsche geologische Gesellschaft. Zeitschrift. Band xxxiv. Hefte 1–4. 1882.

A. Halpar. Ueber ein grosses *Conocardium* aus dem Devon des Oberharzes, 1.—E. Dathe. Beiträge zur Kenntniss des Granulits, 12.—F. M. Stapf. Geologische Beobachtungen im Tessinthal, 41, 54.—A. Heim. Der Bergsturz von Elm, 74.—A. Remelé. Ueber einige gekrümmte untersilurische Cephalopoden, 116.—G. Schweinfurth. Zur Beleuchtung der Frage über den versteinerten Wald, 139.—F. Sandberger. Ueber Bimsstein-Gesteine des Westerwaldes, 146.—R. Nasse. Bemerkungen über die Lagerungsverhältnisse der metamorphischen Gesteine in Attika, 151.—F. Nötling. Ueber *Lituities lituus*, Montfort, 156.—F. Maurer, Ueber das Alter des Hercyn, 194.—H. Credner. Die Stegocephalen aus dem Rothliegenden des Plauen'schen Grundes bei Dresden, 213.—H. B. Geinitz. *Kreischeria Wiedei*, H. B. Gein., ein fossiler Pseudoscorpion aus der Steinkohlenformation von Zwickau, 238.—Schröder. Ueber senone Kreidegeschiebe der Provinzen Ost- u. Westpreussen, 243.—C. Ochsenius. Geologisches und Montanistisches aus Utah, 288.—F. Klockmann. Beitrag zur Kenntniss der granitischen Gesteine des Riesengebirges, 373.—Röding. Die Erzgänge von Innai, 427.—A. Rothpletz. Nachtrag zu dem Aufsatz "Der Bergsturz von Elm," 430.—E. Dathe. Variolite der Gabbrogruppe in Schlesien, 432.—Schenk. Ueber fossile Hölzer Aegyptens, 434.—A. Heim. Ueber den Bergsturz von Elm, 435.—J. Felix. Ueber tertiäre Laubhölzer, 439.—A. Jentzsch. Ueber rothe Quarze in preussischen Gesteinen, 440.—Bölsche. Ueber das Diluvium bei Osnabrück, 442.—M. Neef. Ueber seltenere krystallinische Diluvialgeschiebe der Mark, 461.—H. Credner. Ueber die Genesis der granitischen Gänge des sächsischen Granulitgebirges, 500.—F. Karsch. Ueber ein neues Spinnenthier aus der schlesischen Steinkohle und die Arachniden der Steinkohlenformation überhaupt, 556.—F. Wahnschaffe. Ueber einige glaciale Druckerscheinungen im norddeutschen Diluvium, 562.—G. Böhm. Ueber die Beziehungen von *Pachyrhina* zu *Megalodon*, *Diceras* und *Caprina*, 602.—G. Böhm. Zur Kritik der Gattung *Præconia*, 618.—Hamm. Beobachtungen im Diluvium der Umgegend von Osnabrück, 629.—Berendt. Ueber das Diluvium von Osnabrück und Halle, 637.—O. Heer. Ueber *Sigillaria Preuiana*, Römer, 639.—C. W. Gümbel. Ueber die Bildung der Stylolithen und über Fulgurite, 642.—T. Sterzel. Ueber die Fruchthären von *Annularia sphenophylloides*, Zenker, sp., 685.—G. Gürich. Beiträge zur Kenntniss der niederschlesischen Thonschieferformation, 691.—R. Beck. Das Oligocän von Mittweida, mit besonderer Berücksichtigung seiner Flora, 735.—G. Klemm. Mikroskopische Untersuchungen über psammitische Gesteine, 771.—F. Sandberger. Das Alter der Bimsstein-Gesteine des Westerwaldes und der Lahngegend, 806.—T. Liebe. Ueber diluviale Eisbedeckung in Mitteldeutschland, 812.

Berlin. Deutsche geologische Gesellschaft. Zeitschrift. Band xxxv. Heft 1. 1883.

D. Brauns. Ueber japanische diluviale Säugethiere, 1.—J. Felix. Untersuchung über fossile Hölzer, 59.—W. Dames. Hirsche und Mäuse von Pikermi in Attica, 92.—W. R. Næssig. Die jüngeren Eruptivgesteine des mittleren Elba, 101.—A. Rothpletz. Zum Gebirgsbau der Alpen beiderseits des Rheines, 134.—T. Tschernyschow. Ueber einem im Gouvernement Sarátow im Juli 1882 gefallenen Meteorit, 190.—F. Sandberger. Ueber Zirkon in geschichteten Felsarten, 193.—H. Kunisch. Ueber den ausgewachsenen Zustand von *Encrinurus gracilis*, Buch, 195.—K. Picard. Ueber eine neue Crinoiden-Art aus dem Muschelkalk der Hainleite bei Sondershausen, 199.—T. Sterzel. Ueber *Annularia sphenophylloides*, Zenker sp., 203.—H. B. Geinitz. Ueber *Kreischeria Wiedei*, *Annularia sphenophylloides*, und über Kreidepetrefacten von West-Borneo, 204.—A. Remelé. Ueber das Herkommen der Geschiebe von Macrouruskalk und über einige Bornholmer Geschiebe, 206.—A. von Könen. Ueber Clymenien bei Bicken, 208.

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A. Nehring. Ueber den sogenannten Wolfszahn der Pferde im Hinblick auf den genealogischen Zusammenhang der fossilen und lebenden Equiden, 31.—A. Nehring. Einige nachträgliche Bemerkungen über den Wolfszahn der Equiden, 47.—A. Nehring. Ueber Ulna und Fibula der Equiden, 50.—A. Nehring. Vorlegung einiger fossiler Wildesel-Reste aus dem Diluvium von Westerregeln, 33.—W. Dames. Ueber das Vorkommen fossiler Hirsche in den Pliocänablagerungen von Pikermi in Attika, 71.

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H. Burmeister. *Nothopus priscus*, ein bisher unbekanntes fossiles Faulthier, 613.—J. Roth. Zur Kenntniss der Ponza-Inseln, 623.—W. Dames. Ueber den Bau des Kopfes von *Archaeopteryx*, 817.

——. ———. ———, 1883. Nos. 1–21. 1883.

W. Dames. Ueber eine tertiäre Wirbelthierfauna von der westlichen Insel des Birket-el-Qurūn im Fajum (Aegypten), 129.—E. Reusch. Ueber eine neue Spaltungsrichtung am Gypsspath, 259.

——. Paläontologische Abhandlungen (W. Dames und E. Kayser). Band i. Heft 1. 1882. *Purchased*.

C. Struckmann. Neue Beiträge zur Kenntniss des oberen Jura und der Wealdenbildungen der Umgegend von Hannover, 1.

Birmingham. Mason Science College. Calendar for the Session 1882–1883. 1882.

——. Midland Naturalist. Vol. v. No. 59. 1882. *Presented by W. Whitaker, Esq., F.G.S.*

——. ———. Vol. vi. No. 63. 1883. *Presented by W. Whitaker, Esq., F.G.S.*

Bologna. Congrès Géologique International. Compte rendu de la 2<sup>me</sup> session. Bologne, 1881. 1882. *Presented by Prof. J. Capellini.*

J. Szabó. Classification macrographique des Trachytes de la Hongrie,

211.—J. G. Bornemann. Sur la classification des formations stratifiées anciennes de l'Ile de Sardaigne, 221.—G. Rolland. Sur le terrain crétacé et sur les grandes dunes de sable du Sahara septentrional, 233.—C. S. Wilkinson. Mémoire sur la géologie de la nouvelle Galles du Sud, 236.

Bologna. Reale Università. Catalogo dei lavori pubblicati dai Professori, dai Dottori Collegiati e dagli assistenti, 1864-74. 1875. *Presented by Prof. G. Capellini.*

Bordeaux. Société Linnéenne. Actes. Vol. xxxv. 1881.

P. Fischer. Cétacés du Sud-ouest de la France, 1 (Mémoires).—E. Benoist. La coupe des carrières de Cenon, i. (Procès-Verbaux).—Degrange-Touzin. Les marnes à Cérîtes et Cyrènes de Saint-Côme, xii.—E. Benoist. Une excursion géologique à Castillon-sur-Dordogne, xx.—E. Benoist. Une excursion géologique à Montagoudin et Mongauzy (environs de la Réole), xxiii.—E. Benoist. Le lambeau tertiaire de Saint-Palais près Royan, xxviii.—E. Benoist. Excursion géologique à Bouzac, près Guîtres, xxxi.—Cabanne. Essai chimique et au chalumeau du minéral signalé dans le falun de Salles par M. Degrange-Touzin, li.

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W. H. Melville. Crystalline Form of Cryolite, 55.

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S. H. Scudder. Archipolypoda, a Subordinal Type of Spined Myriapods from the Carboniferous Formation, 143.

—Proceedings. Vol. xxi. Parts 2 & 3. 1882.

M. E. Wadsworth. The Appropriation of the name Laurentian by the Canadian Geologists, 121.—C. C. Abbott. An Historical Sketch of the Discoveries of Palæolithic Implements in the Valley of the Delaware, 124.—H. W. Haynes. The Argillite Implements found in the Gravels of the Delaware River, at Trenton, N. J., compared with the Palæolithic Implements of Europe, 132.—G. F. Wright. An Attempt to estimate the Age of the Palæolithic-bearing Gravels in Trenton, N. Y., 137.—J. W. Dawson. Note on *Spirorbis* contained in an Ironstone Nodule from Mazou Creek, with Millipede, 157.—N. S. Shaler. On the Recent Advances and Recessions of Glaciers, 162.—M. E. Wadsworth. A Microscopic Study of the Cumberland Iron Ore of Rhode Island, 194.—W. W. Dodge. Notes on the Geology of Eastern Massachusetts, 197.—N. F. Merrill. Concerning the Lithological Collection of the Exploration of the 40th Parallel, 234.—M. E. Wadsworth. Some Points relating to the Geological Exploration of the 40th Parallel, 243.—M. E. Wadsworth. On the Relation of the Quincey Granite to the Primordial Argillite of Braintree, Massachusetts, 274.—W. O. Crosby. On the Classification of the Textures and Structures of Rocks, 279.—M. E. Wadsworth. On the Trachyte of Marblehead Neck, Massachusetts, 288.—W. M. Davis. On the Classification of Lake Basins, 315.

Bristol Museum and Library. Report of Proceedings at the Twelfth Annual Meeting, held 15th February, 1883.

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